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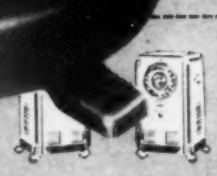
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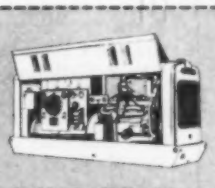
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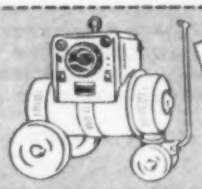
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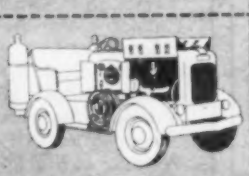
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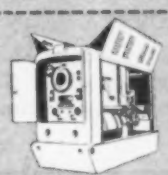
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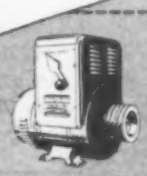
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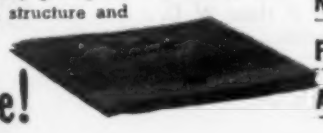

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Published for the Advancement of the Science and Art of Welding

W. SPRARAGEN, Editor

OCTOBER 1947

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COVER

Welding Freight Car in an Upside Down Position in Rotary Jig. *Courtesy American Car and Foundry Company.*

ISSUED MONTHLY

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Subscriptions $5.00 per year in United States and possessions; Foreign Countries $7.00. Single copies, non-members $.75; Special issue October $1.00; members 50 cents.

Entered as second-class matter January 15, 1932, at the post-office at Easton, Pa., under the act of March 3, 1879.

PUBLICATION OFFICE
20th & Northampton Streets, Easton, Pa.
EDITORIAL AND GENERAL OFFICES
33 West 39th St., New York 18, N. Y.

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The Journal of
The American Welding Society
VOLUME 26 · NUMBER 10 · OCTOBER 1947

Problems in Resistance Welding Stainless Steel Railway Car Structures*

By J. H. Van den Beemt†

WE KNOW that "necessity is the mother of invention," but what is "necessity?" We have all had some experience with necessity, such as, when our management or our competitors force demands upon us; and the more unreasonable the demands the more impelling the necessity. But today we must realize another necessity. We must, as a nation, produce more efficiently than ever before to maintain our standard of living. The time has passed when labor can be expected to work as it did in the depression '30's. Production per man-hour has decreased and we must make up the deficit with more efficient equipment. Great progress has been made in welding, which is generally considered the most economical method of fabrication, and the AMERICAN WELDING SOCIETY has played a prominent part in stimulating that progress. However, as you well know, there are still many problems. There is much progress to be made.

* Scheduled for Twenty-Eighth Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 19, 1947.
† Welding Engineer, The Budd Co., Philadelphia 15, Pa.

While this brief review of the procedure and methods employed in the assembly of stainless steel railway cars will be interesting, the purpose of the review is not to elaborate on any contributions we have made to the art of science of welding, but rather to point out some "necessities" where contributions can be made.

In 1929 it became apparent to The Budd Co. that the strength of 18% Cr and 8% Ni austenitic stainless steel could be increased by cold working from 90,000 psi. to much higher strengths without lowering its ductility to a point where it could not be formed into useful shapes. This fact, together with the development of the Shotweld Process, has made possible the design and manufacture of our modern corrosion-resistant railway car and truck trailer structures. Many problems had to be solved before this industry became a reality. This was accomplished by courage and imagination.

Two basic principles are followed in the assembly of these structures: (1) the material is used most advantageously when spot welded by the Shotweld Process and

The First Production Dome Car to Be Delivered from the Assembly Line of Any Railroad Car Manufacturer

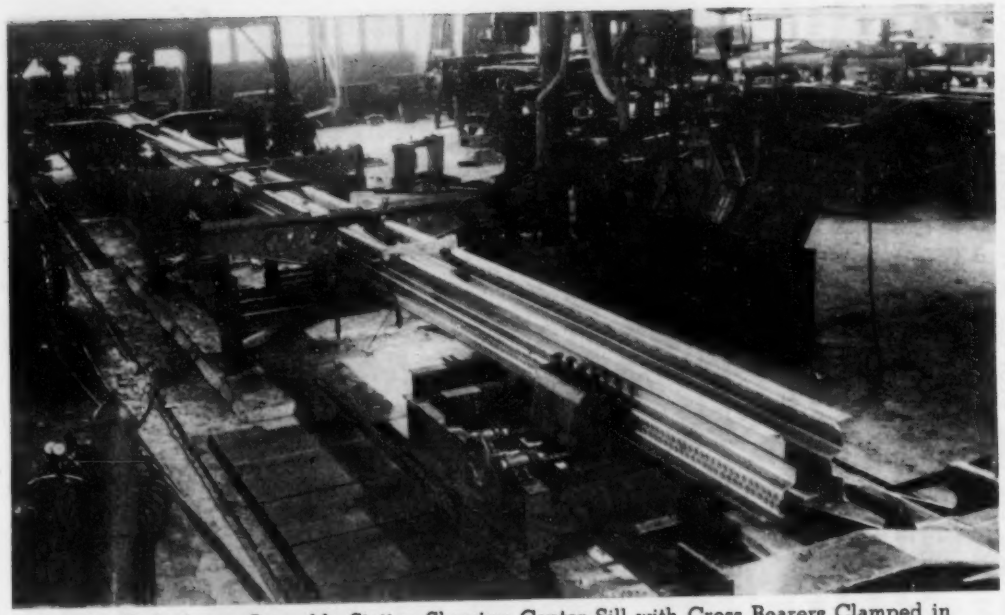


Fig. 1—Underframe Assembly Station Showing Center Sill with Cross Bearers Clamped in Position for Welding and End Underframe Ready to Be Pressed Into Position on the Ends of the Center Sill

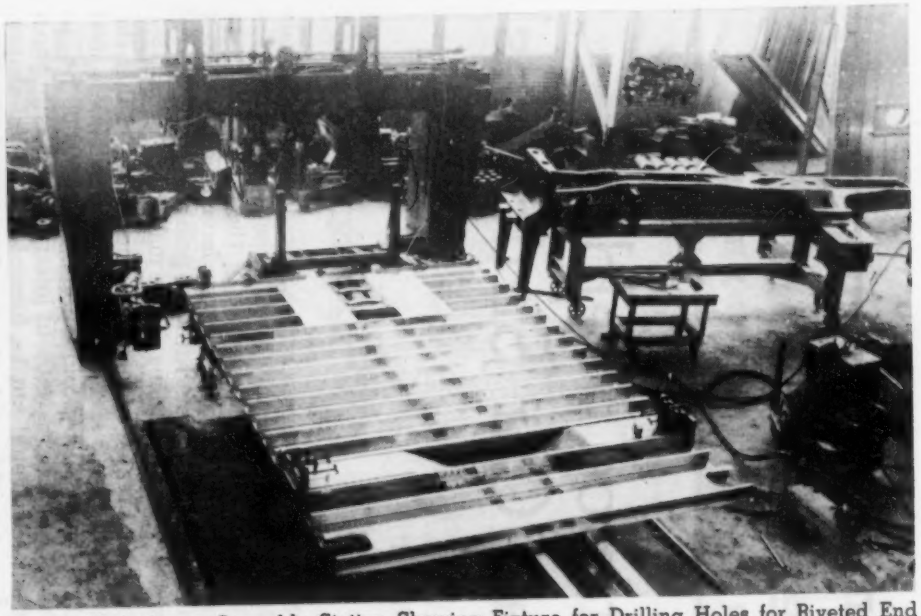


Fig. 2—Underframe Assembly Station Showing Fixture for Drilling Holes for Riveted End Underframe to Center Sill Connection, End Floor Pan Group Plug Arc Welded Into Position and in the Right Background a Complete End Underframe Assembly in Inverted Position

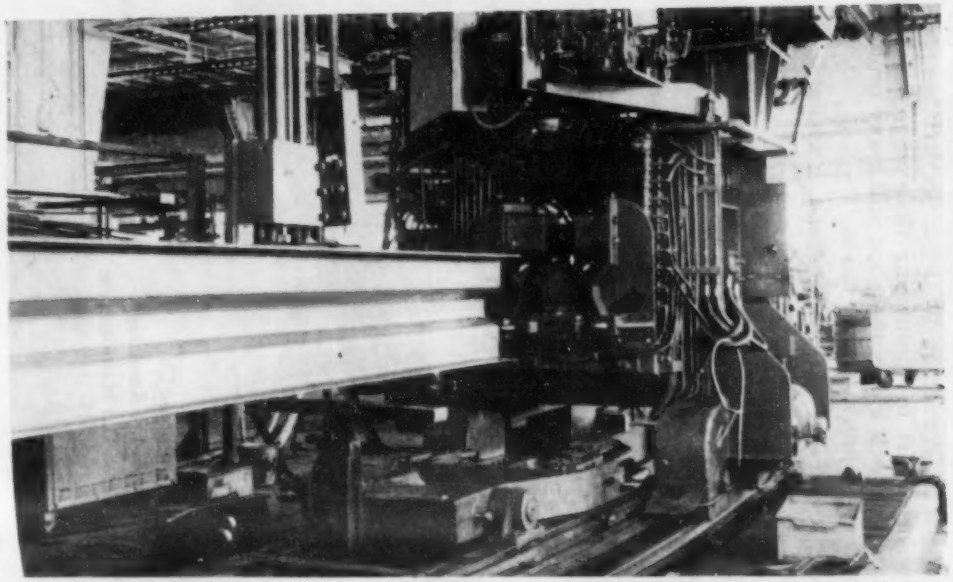


Fig. 3—Center Sill Welder, Center Sill in Position to Enter Machine and Machine Ready to Advance Over First Jig Clamp

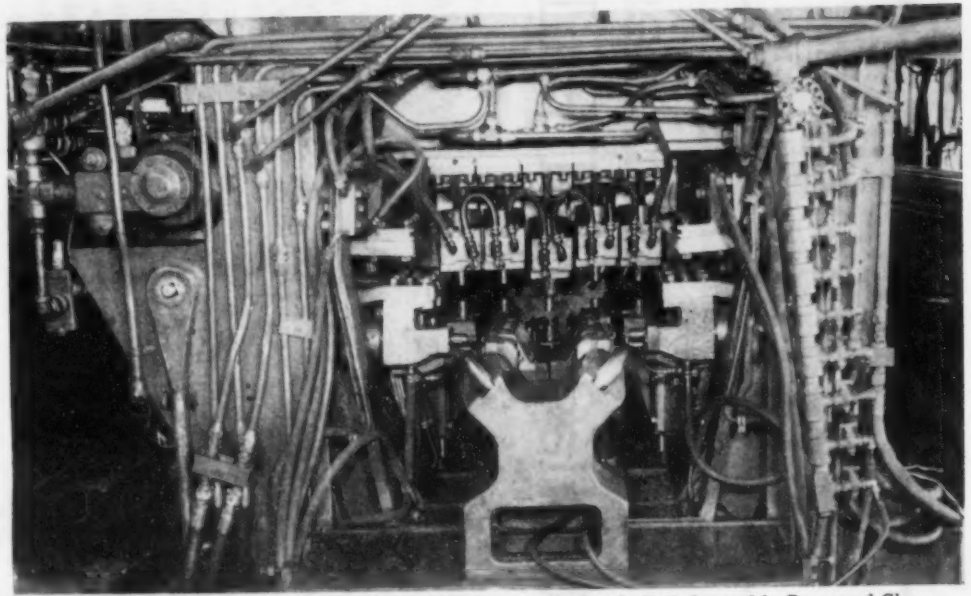


Fig. 4—Center Sill Welder, Close-Up of Machine with Guide Roll Assembly Removed Showing 9 Pairs of Welding Electrodes

Fig. 3—Center Sill Welder, Center Sill in Position to Enter Machine and Machine Ready to Advance Over First Jig Clamp

Fig. 4—Center Sill Welder, Close-Up of Machine with Guide Roll Assembly Removed Showing 9 Pairs of Welding Electrodes

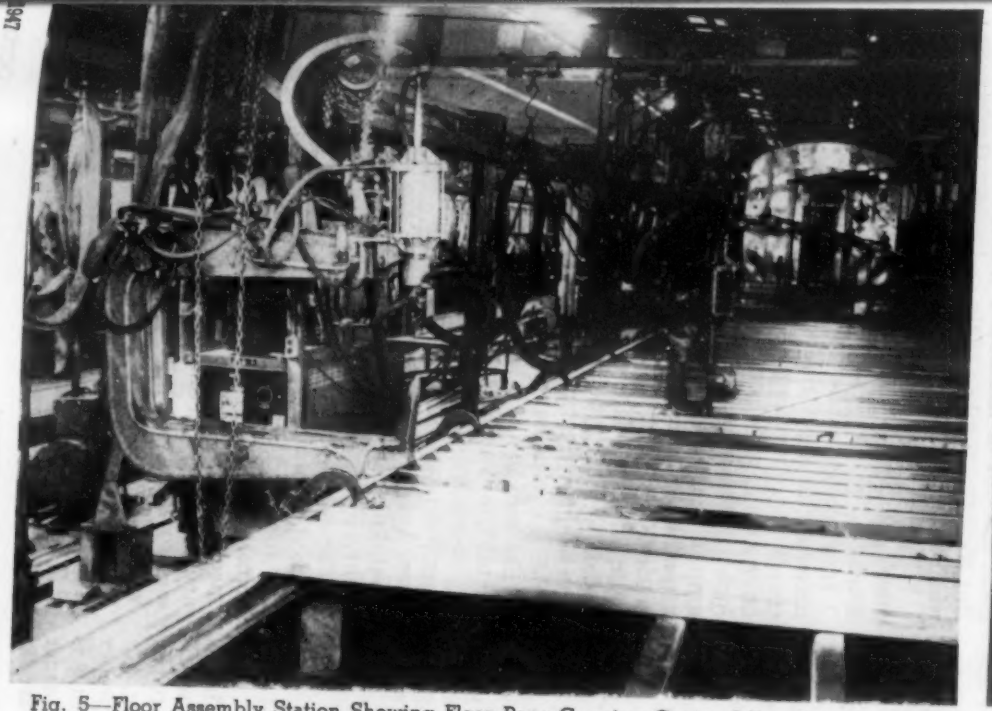


Fig. 5—Floor Assembly Station Showing Floor Pans Crossing Center Sill and Nesting Into Side Sill and Some of the Welding Tools Used on This Station

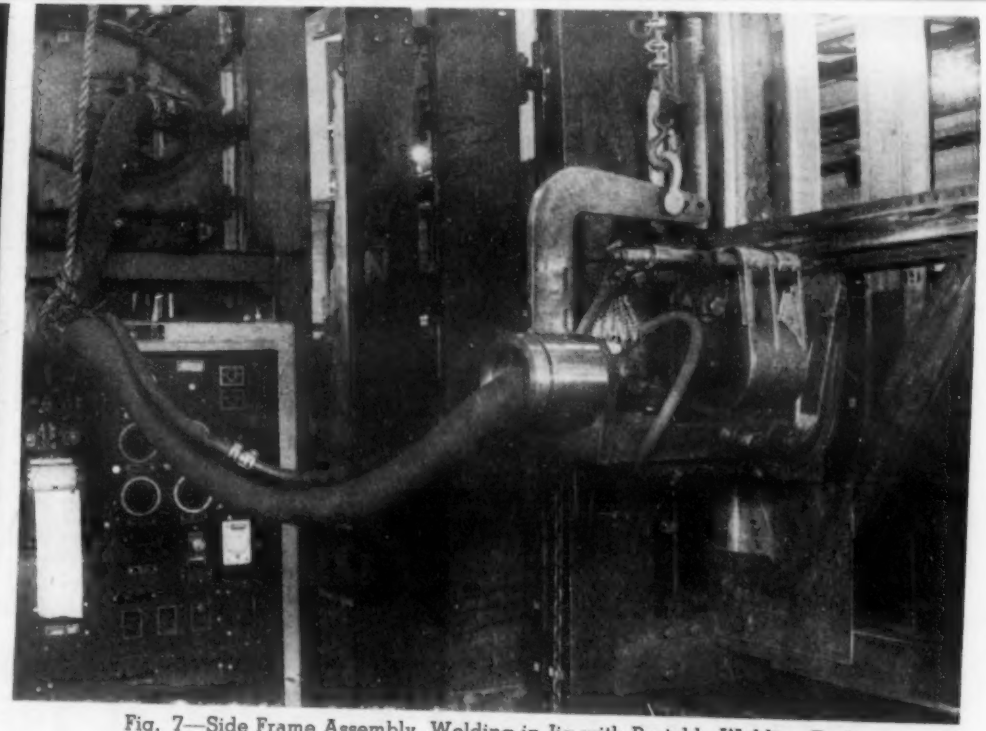


Fig. 7—Side Frame Assembly, Welding in Jig with Portable Welding Tool

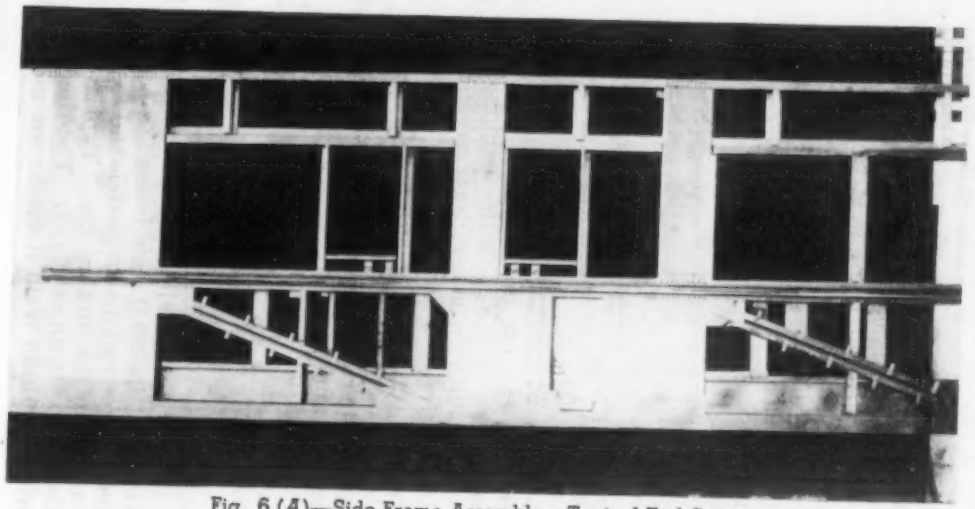


Fig. 6 (*A*)—Side Frame Assembly; Typical End Section

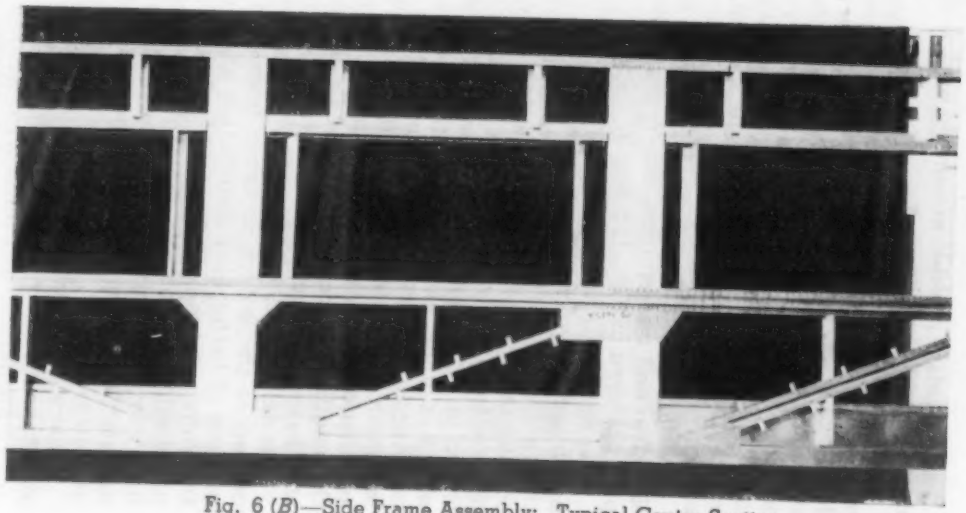


Fig. 6 (*B*)—Side Frame Assembly; Typical Center Section

(2) the greatest possible amount of work is always completed in subassembly.

We assemble a railway car by prefabricating, as nearly completely as possible, six major assemblies: namely, floor, two sides, two ends and a roof. These units are assembled into a car. This car structure is then mounted on dummy trucks and moved along the finish line for installation of trim and appointments. When the car leaves the plant it is completely finished, ready for service.

The floor assembly consists of a center sill, two side sills, two end underframes, two cross bearers and floor pans as shown in Figs. 1, 2, and 5.

The center sill is a welded assembly made of 4 drawbench sections of 0.203-in. stainless steel. These sections are welded together with 9 rows of welds at $2^1/_2$ in. spacing or approximately 2700 welds. This welding is done automatically in less than 4 hrs. on the machine shown in Figs. 3 and 4. Each weld is pulsation welded with 1-in. diam. electrodes, exerting a force of 5500 lb., carrying a current of 23,000 amp. Each weld has a minimum shear strength of 20,000 lb. The welder is automatically indexed along a track and travels 60 ft., the length of the center sill. The jig clamps drop down and the machine passes over them as shown in Fig. 3.

The weld power, delivered to two transformers mounted on top of the welder, is taken from two phases, for purpose of better load distribution and is controlled by two fully synchronous electronic weld timers employing phase-shift heat control. Each of these timers has three heat control circuits automatically selected to accommodate the various impedance conditions of the secondary bus system.

Timers of this type, used exclusively in our stainless steel operations, are equipped with sequence control, voltage compensation and Budd Weld Recorder. They are fine precision controls and while not quite as complex as stored energy timers, they still require highly skilled maintenance personnel. There is a great need for a simple, yet reliable, flexible synchronous timer.

The cross bearers are welded to the center sill with a portable hydraulic tool as shown in Fig. 1. This tool has a reach of 17 in., exerts a tip force of 3300 lb. and is capable of delivering approximately 15,000 amp. to the weld. It produces a weld of 6300 lb. minimum shear strength in 0.090-in. stainless steel.

Floor pans, which have been previously subassembled into groups, are welded to the center sill and side sill with portable tools shown in Fig. 5. These tools, delivering up to 3600 lb. tip force, require in some cases close front clearances, and in others a long retraction stroke, swivel cutout electrodes and deep 56-in. yokes. The transformer is of necessity quite high overhead, presenting a support and handling problem and requiring a high secondary voltage with the resulting high primary demand. With the new high temperature resistant insulation materials which are now available, possible small transformers could be built into large yokes of this type. Current compensators could adjust for variations in output due to resistance heating. Something of this nature would be most useful.

The finished floor structure as shown in Fig. 13 is then inverted and all underfloor equipment is installed in a convenient working position.

The side frame is completely spot-welded stainless steel truss type structure as shown in Fig. 6 *A* and *B*. Much of this welding is done in subassembly of parts. However, the 80-ft. side frame is assembled in a jig, adjustable for various car models and to produce the proper camber in the finished car. Typical of this welding is the setup shown in Fig. 7. The timer and transformer with the Budd Weld Recorder are mounted on a truck. The tool is hung from an overhead rail and counterbalanced for $8^1/_2$-ft. vertical travel from top to bottom of the side frame. The tool hanger allows the tool to weld with the electrodes as shown, or to rotate 180° to perform the welding shown on gusset below the tool.

Two of the major problems encountered in welding this assembly are cable weight and tip replacement. As the tool is moved from the top to the bottom welding position, the weight of the cable applied to the tool varies considerably. Low reactance cables and lugs, of a fatigue-resistant light-weight alloy would be ideal for this operation, provided a surface preparation producing low contact resistance could be developed. It would be almost essential that such surfaces be easily replaced the user of the cable.

The extremely narrow tip clearances make it necessary to solder small tips to these welding tools, a slow and undesirable operation. Longer lasting tips would be most valuable. For the past 10 yr. we have been using the same tip materials. With the great strides that have been made in other branches of metallurgy during this period, is it possible that welding electrode tip materials cannot have been improved? No doubt someone has tried a soft, high conductivity overlay on a hard deformation-resistant back, but there must be other approaches.

The end frame consisting of end sheets and collision posts is assembled in a jig with portable tools. See Fig. 8. This is a typical portable welding tool installation in three respects:

1. It is necessary to hang more than one tool from the transformer with the resulting tangle of power, air, water and control lines. There is a crying need for simplification of this jungle.

2. The X type tool could be made much lighter and easier to handle if made from light-weight alloy; there is a great amount of unstressed metal in this type of tool. But then the problem of tip and cable attachment arises when aluminum alloys are used.

3. With C type tools of large yoke sizes, bad reactance conditions are unavoidable with the equipment now available.

In some assemblies where welding is done, it is also necessary to apply rivets. We have met with some success in forge riveting with portable welding tools which have a concaved electrode tip to form a rivet head. Half-inch rivets are being forged with approximately 18,000 amp. applied for 30 cycles on, 5 cycles off, 5 shots and, after 2 shots, when the rivets are fully heated, the electrode force is increased from 3500 to 7000 lb. There are little published data on set-up values and electrode materials for this type of work. Are many manufacturers investing in riveting and welding equipment when the welding equipment could do both jobs?

The roof is assembled in a cambered jig which is adjustable for various types of cars. Portable welding tools are necessary to provide flexibility of equipment. The essential parts of the roof structure are transverse carlines, longitudinal purlines and corrugation assemblies, all stainless steel. Figure 9 shows these parts and equipment.

The lower corrugation on the sides of the roof are backed by a reinforcing plate and serve as a tie between the roof and side frame assemblies. These parts and some of the roof corrugation seams are roller welded on a special welder, Figs. 10 and 11. The welder is stationary and the 80-ft. one-piece corrugations are welded from end to end as they are driven past the floating welding wheels by drive rolls. Comb pads guide the corrugations, hold them in line and prevent damage by the drive rolls.

There are thousands of feet of roller welding on a railway car. We use seven such welders, including two

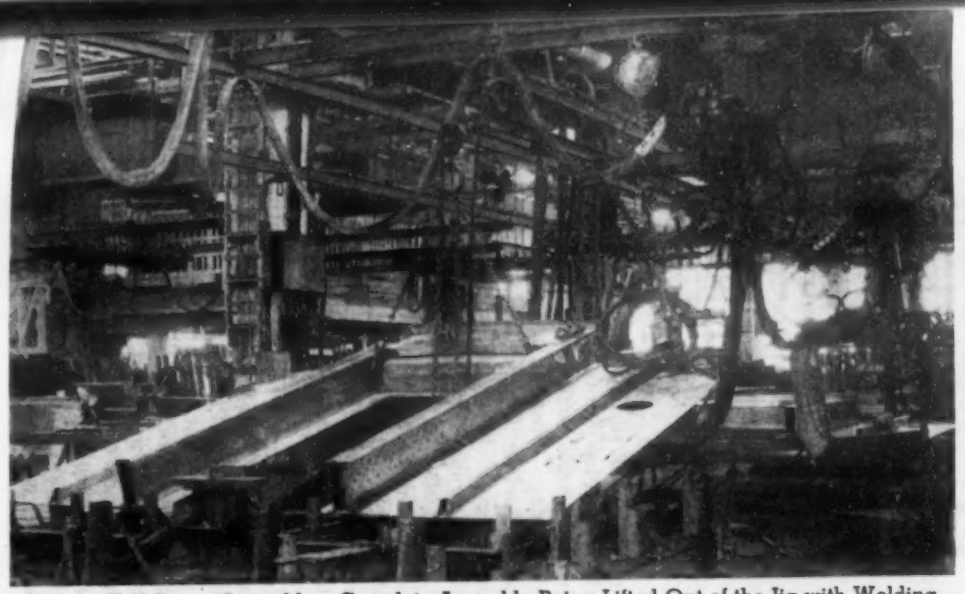


Fig. 8—End Frame Assembly; Complete Assembly Being Lifted Out of the Jig with Welding Tools in the Background

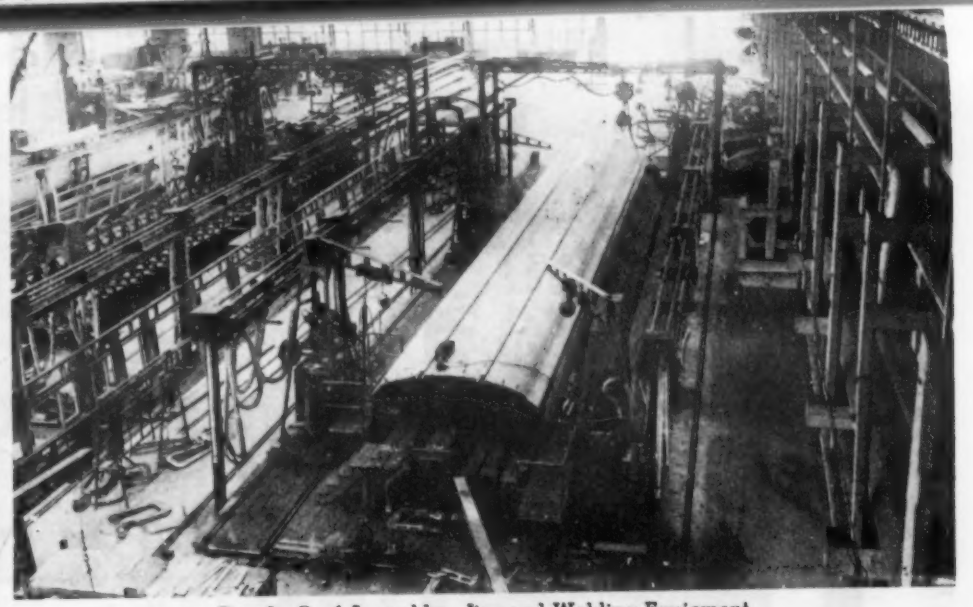


Fig. 9—Roof Assembly; Jigs and Welding Equipment

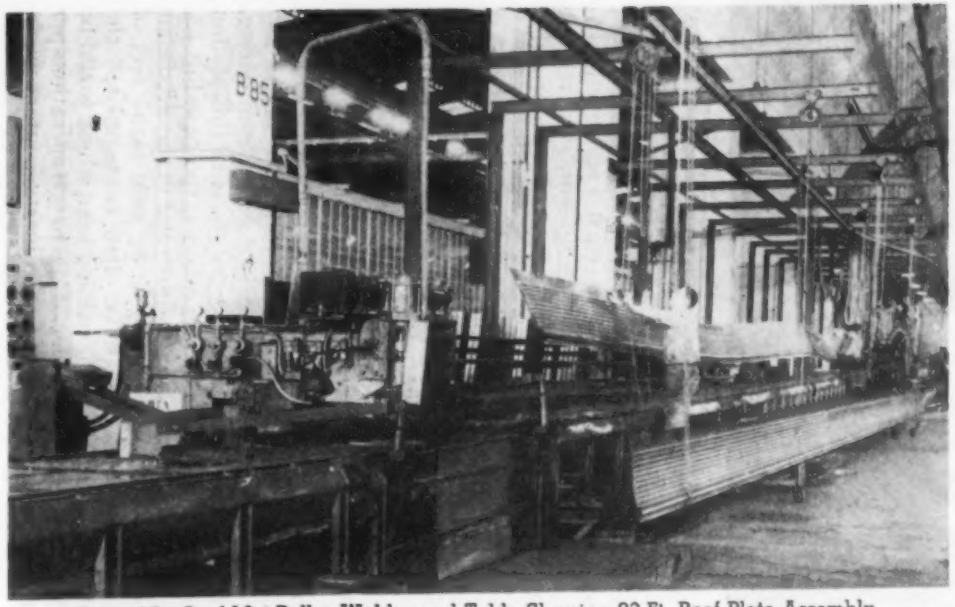


Fig. 10—Roof Mat Roller Welder and Table Showing 80-Ft. Roof Plate Assembly

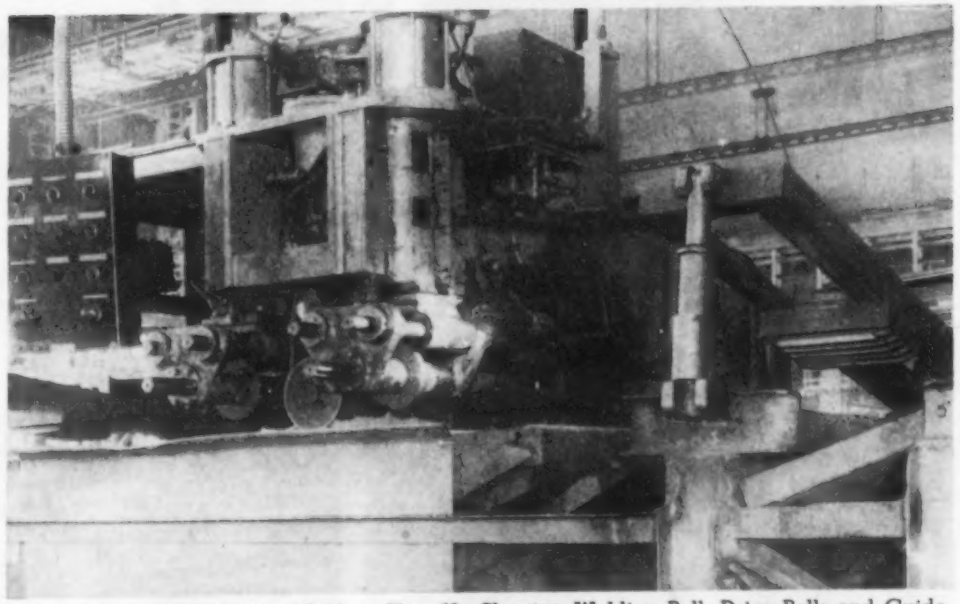


Fig. 11—Roof Mat Roller Welder, Close-Up Showing Welding Roll, Drive Rolls and Guide Comb Pads

Fig. 12—Roof Trim Station Where Air Ducts, Insulation, Piping, Vent Ducts and Miscellaneous Equipment Are Installed

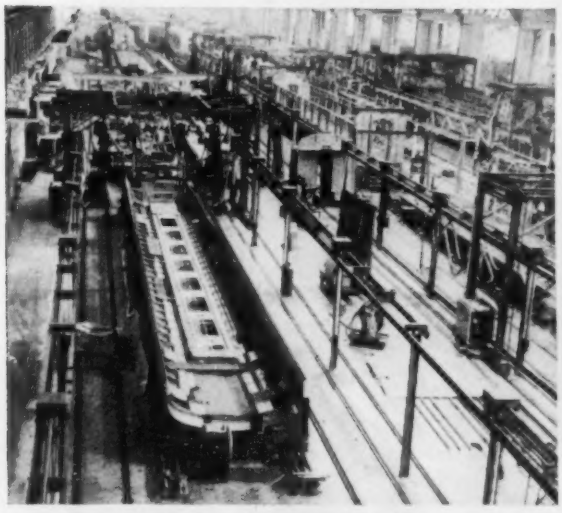
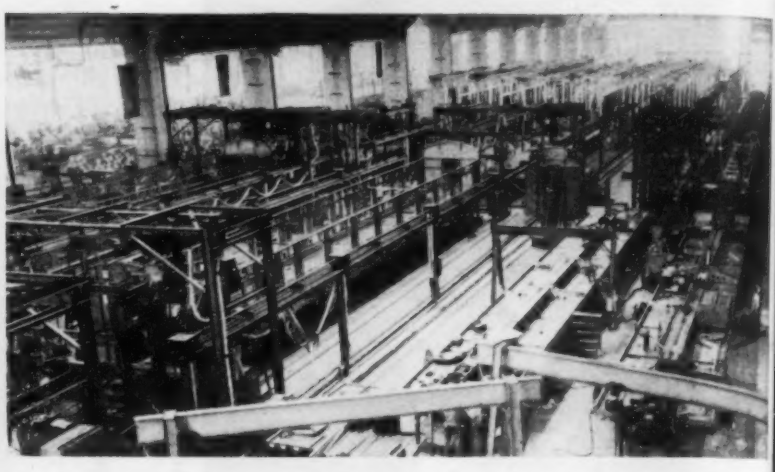


Fig. 13—Under Floor Equipment Installation on Right; Assembly of Floor, Sides and Ends on Left



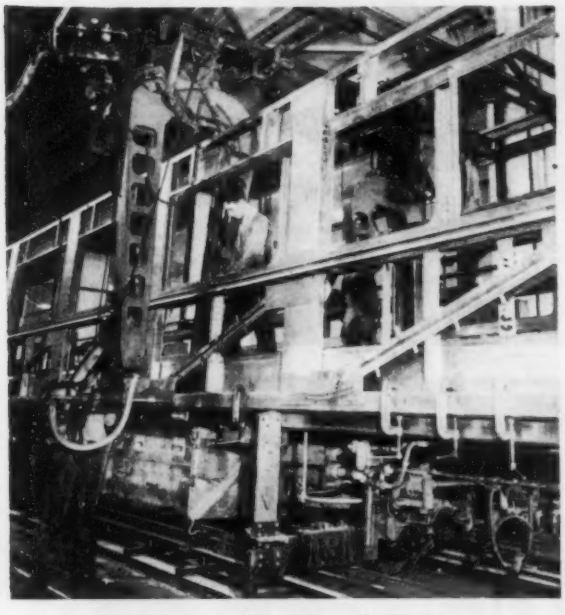


Fig. 14—Welding Side Frame to Floor Structure

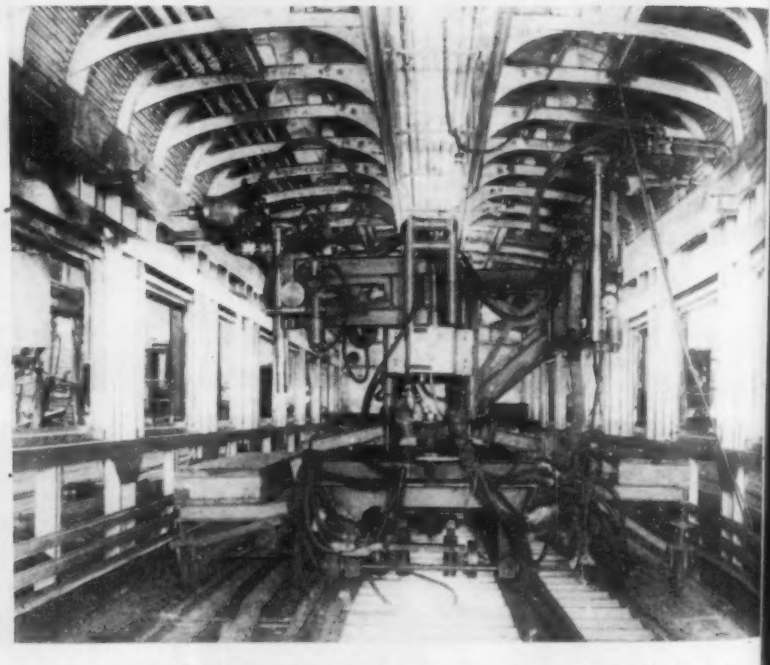


Fig. 15—Welding Roof to Side Frame with "Octopus" Welding Truck

portable roller seam welding tools, and we look forward to the day when a technique is developed which will produce welds made at $^1/_2$ cycle spacing, which are reliable under stress and do not require primers for water tightness.

Another problem in roller welder operation is roll shaft bearing life. Most machines are built with bushings, which must be lubricated to carry mechanical load and still conduct electricity at high current density. Have the possibilities of copper alloy roller bearings, carbon copper brush or mercury pool current take-off devices been fully explored?

After the roof structure is completed it is inverted and placed in a cradle, a convenient position to install air-conditioning equipment, insulation, piping and wiring, and finish trim. The welding operations in this station are accomplished in a normal position as shown in Fig. 12.

In both roof assembly operations and in miscellaneous subassembly welding operations, we weld many feet of straight flat metal. We have often contemplated the possibilities of developing a welding head which would be capable of speeds in the order of 300 to 400 operations per minute. This head would have an inertia contact mechanism for weld initiation and would utilize electrode inertia for electrode force. Some sort of shuttle indexing mechanism would be required to advance the work through the electrodes. Possibly a device similar to that used on a sewing machine. Visualize the possibilities presented by this dream. It is well worth serious consideration.

Another device closely related to the inertia tip force head would allow spot welding with an electrode on only one side of the sheets being welded. These methods may be limited to light sheet, and they may require weld cooling instead of weld forging. They upset some of our established doctrines, but remember, nothing is impossible.

The final assembly of the car structure is accomplished in two stations. In the first station, shown in Fig. 13, the end frames and side frames are welded to the fully equipped floor structure. The tool used to weld the side frames to the floor, Fig. 14, are 90 in. deep, develop tip force of 2000 lb. and have a retraction stroke of 6 in. and are hung one on each side of the car and progress simultaneously from one end of the car to the other. If an economical method could be found to copper clad or plate these large welding yokes, which are fabricated from

steel plate, their electrical characteristics could be greatly improved.

In the second station the equipped and partially trimmed roof is applied. The roof connection to the side frame is made by welding tools hung from traveling jib cranes outside the car and by tools supported by a special device inside the car, Fig. 15. This device has been affectionately called "The Octopus." The Octopus, which contains two welding transformers, has an electric motor drive, air motor tool lifts and a 10-ft. spread. It will support interchangeable X type tools and C type tools and can be removed from the car through a 26-in. doorway.

We have, in these operations, an active welding research laboratory. We weld stainless steel, mild steel, low-alloy steel and aluminum. Our equipment includes about a dozen special welders, many pedestal welders, hundreds of portable welding installations and nearly 1000 portable welding tools; and most of this equipment we have designed and built in our own plant. However, those developments which are most valuable to us are not the special $50,000 welders but the little things that apply to all our welding operations. Those developments which are the greatest aid to industry, and frequently bring the greatest return, are simple things. It is not necessary to sell expensive special equipment to make a profit; consider the Smith Brothers.

The day is not far off when we will be able to place any thickness of material between the electrodes of a welder, and an electronic control will automatically adjust the current to the required value and interrupt that current when a weld has formed. This development and many others lie ahead of us. The formula for their accomplishment is courage and imagination.

Shunt Circuit Impedance in Spot Welding 1/8-, 1/4- and 1/2-In. Mild Steel*

By Robert H. Blair†

IN spot welding parts where more than a single weld is used, it is a commonly known fact that contiguous welds frequently do not have the shear strength characteristic of the initial welds. This is due to the fact that the initial weld provides a shunt current path around the contiguous weld so that a greater part of the available secondary voltage appears in the transformer and throat and less across the nugget area of the work impedance. However, since both the weld current and shunt current pass through the electrode contact area of the second weld, the surface heating around the electrode will give a false indication of the nugget size of the second weld. Shunt effect can never be considered to have any advantages in spot welding, but, on the other hand, it need not be any serious disadvantage except when the lack of understanding of the effect of shunt current variables allows one to be mislead by false external sheet appearances.

The magnitude of this 60-cycle shunt effect is affected by such factors as welder impedance, spot spacing, sheet width, location of shunt path with respect to throat field, and sheet temperature.

Figure 1 shows an experimental curve obtained by welding 1/4 in. x 3 in. mild steel with all factors held constant except shunt distance. All welding‡ was done on a Taylor-Winfield ERB-30-150 welder with a synchronous control. Due to the necessary gripping area necessary to shear test welds in this size stock, it was found practically impossible to separately test welds made closer than 2 1/2 in. and for this reason the curve could only be estimated for shunt distances less than 2 1/2 in.

Figure 2 shows a schematic welder circuit having transformer and throat impedance, work impedance and shunt circuit impedance. As the transformer and throat impedance is reduced, the less the percentage of the total available voltage appears in the throat due to the flow of the shunt current. If the welder could have zero

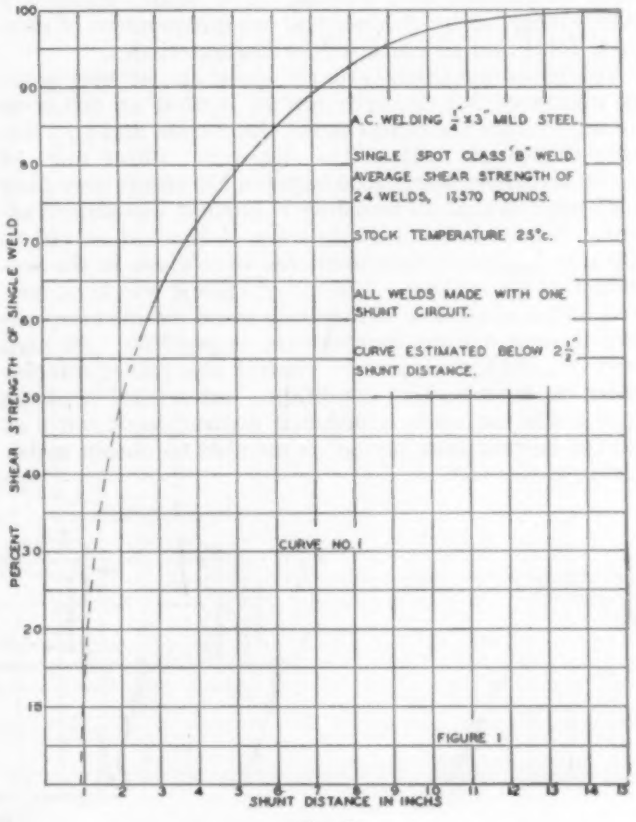


FIGURE 1

Fig. 1

* Scheduled for Twenty-Eighth Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 19, 1947.

† Experimental Laboratory, The Taylor-Winfield Corp., Warren, Ohio.

‡ Reference on Fig. 1 to a Class B weld is made merely to designate a weld schedule built around an electrode force of 10,000 psi. and an electrode diameter equal to the square root of one thickness of sheet and does not infer a second grade weld or a weld inferior to a Class A weld.

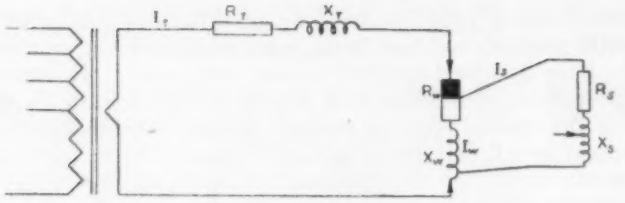


Fig. 2

impedance, the electrode voltage would remain constant regardless of the amount of shunt current and the amount of current loss suffered in the contiguous weld would be measured by the product of the shaded portion of R_W (mainly electrode contact resistance) and I_S. For this reason, under a given set of condtions the magnitude of shunting effect is peculiar to the welder impedance and is less for the low impedance welder than it is for the high impedance machine. Also it is erroneous to say that the shunting effect becomes negligible for a given piece of stock at some shunting distance unless one can also specify such values as the shaded portion of R_W, R_T and X_T.

For purposes of quantitatively determining shunt impedances and of determining the effect of shunt distance, sheet width and stock thickness on the shunt impedance, a series of sheets 24 to 36 in. in length and of various widths was used. These sheets covered the stock thicknesses of $^1/_2$, $^1/_4$ and $^1/_8$ inch. The effective shunt voltage is some voltage existing between the electrode surfaces of the work (probably the average voltage), and in order to avoid the difficulties and errors in measuring this effective voltage, measurements of shunt voltage were made at a distance from the electrode (see Fig. 3). This method was followed consistently in all sheet widths and stock thicknesses and although these shunt voltage measurements do not include the voltage drop of the current concentration area around the electrode (see Fig. 4), they do give good and consistent comparisons between stock thicknesses and widths. Also shunt impedance values recorded by this method are independent of electrode force and size and welder characteristics.

Voltage contact points on the shunt circuit were made by means of No. 2 drive screws located at distances measured from the center of the shunt weld and on a line from the shunt weld to the electrode. Sheet mica of $^1/_{32}$ in. thickness was placed between the sheets over their full length so that all transformer current was shunt current. When shunt currents were of low values (10 to 600 amp.), current measurements were made in the secondary of the welder. The shunt circuit was kept covered with a water flow to maintain shunt circuit temperature as near a fixed temperature as possible. At high currents, stock temperature control was rather difficult under the best cooling conditions, but several readings were made on each impedance measurement with as short a current flow period as possible to obtain meter readings.

Initial welds in all sheets were made according to a Class B schedule. Some thirty impedance curves were plotted showing impedances for shunt paths in various sheet widths and over the range of sheet thickness.

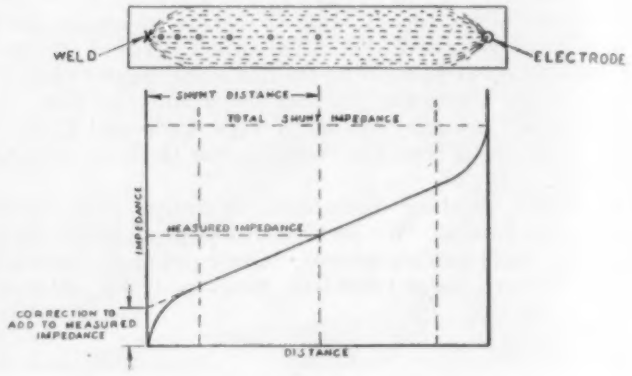


Fig. 4

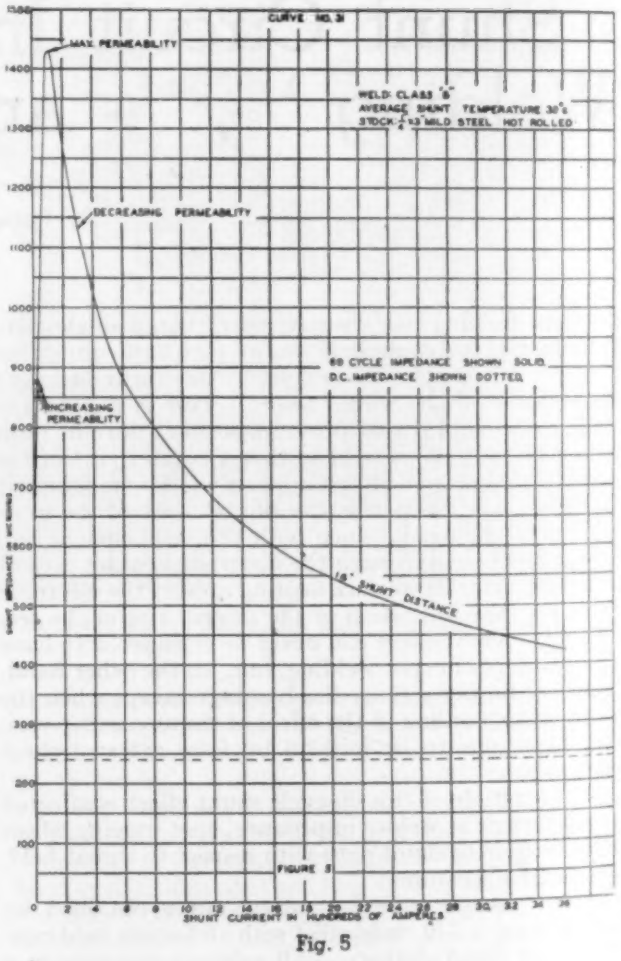


Fig. 5

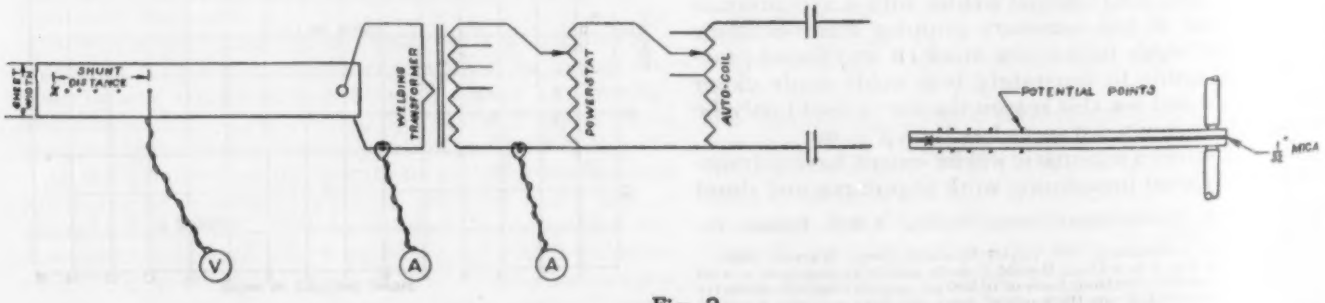


Fig. 3

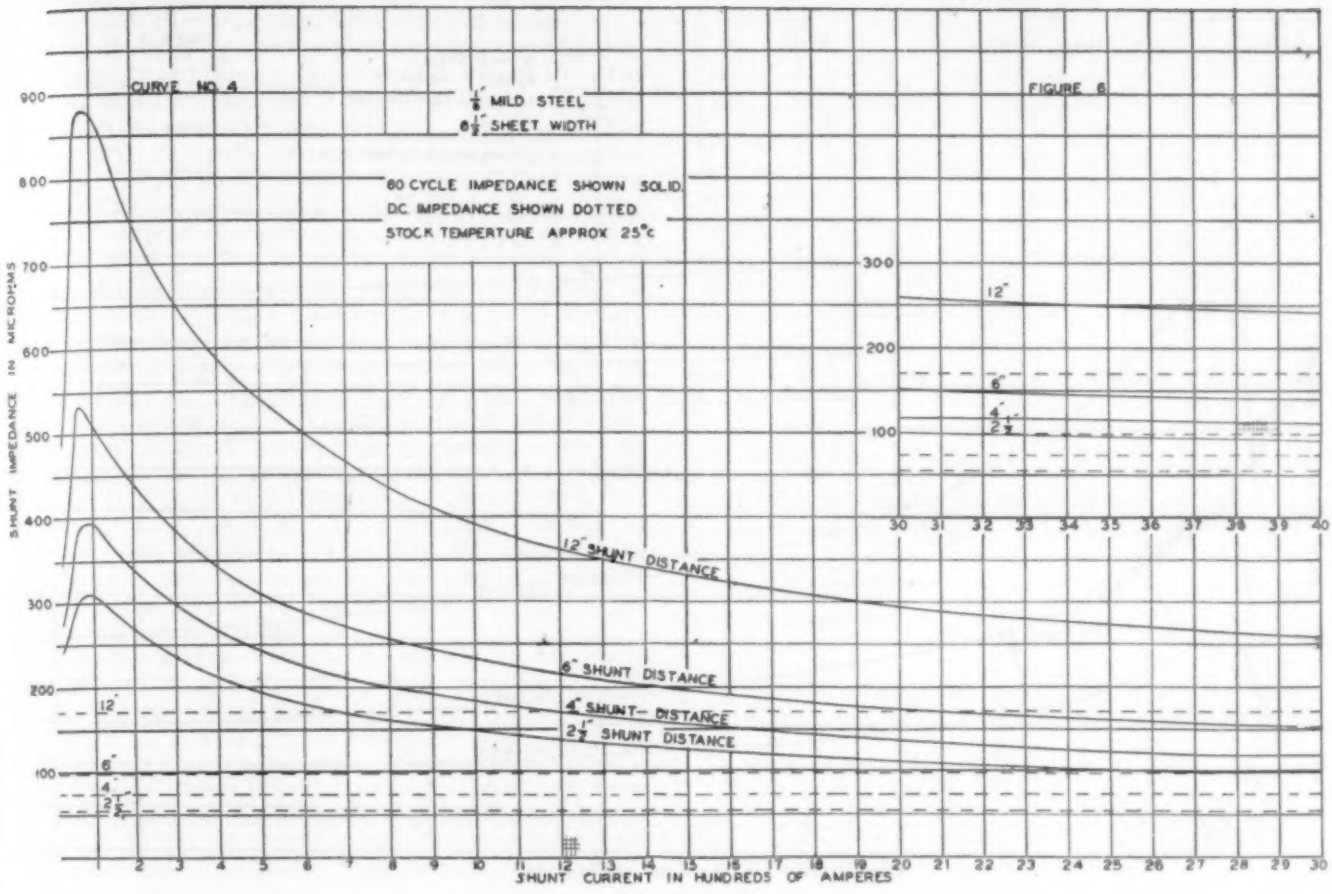

CURVE NO. 4
FIGURE 6
1/4" MILD STEEL
6 1/2" SHEET WIDTH
60 CYCLE IMPEDANCE SHOWN SOLID.
D.C. IMPEDANCE SHOWN DOTTED
STOCK TEMPERTURE APPROX 25°c
SHUNT IMPEDANCE IN MICROHMS
12" SHUNT DISTANCE
6" SHUNT DISTANCE
4" SHUNT DISTANCE
2 1/2" SHUNT DISTANCE
SHUNT CURRENT IN HUNDREDS OF AMPERES

Fig. 6

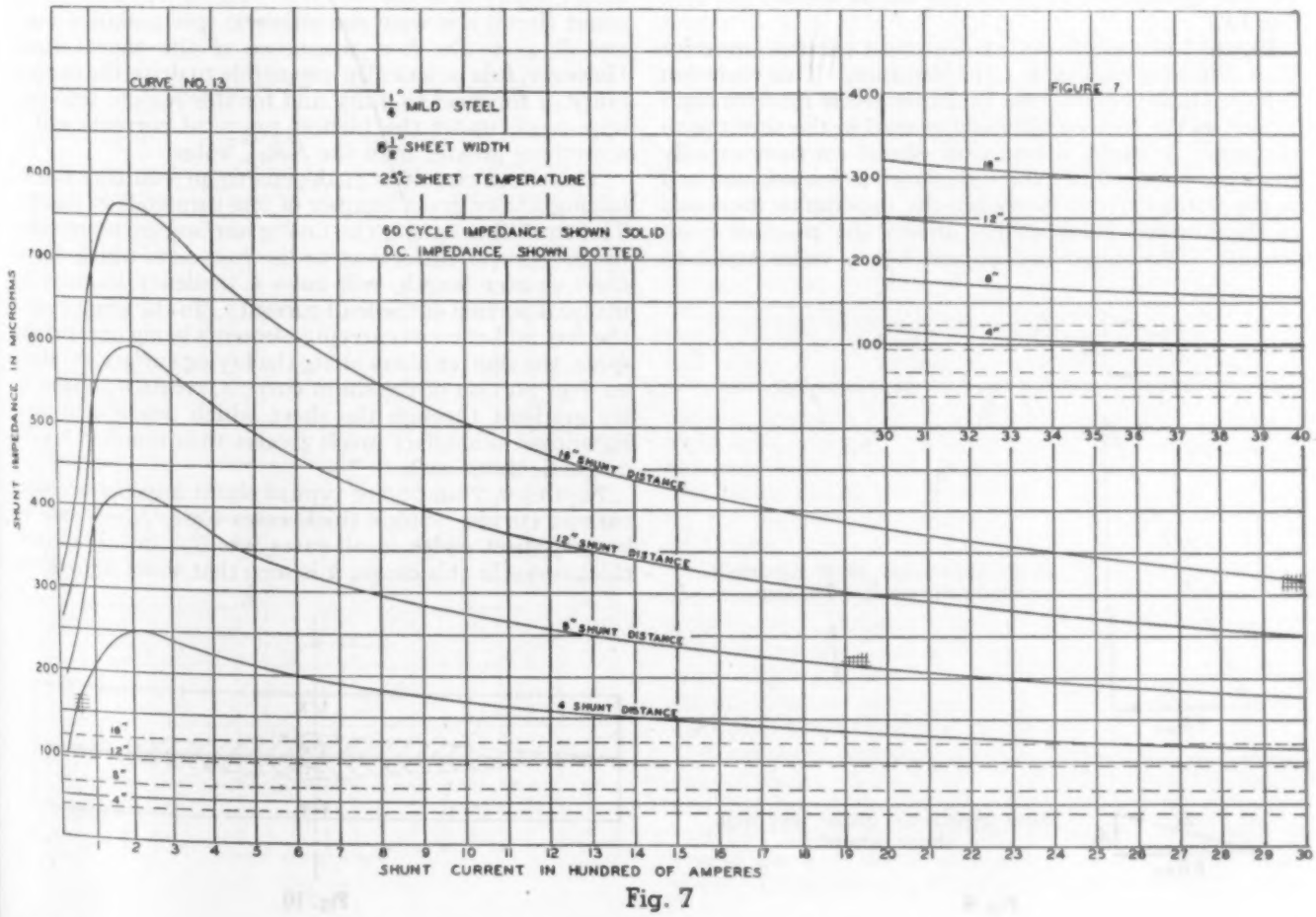

CURVE NO. 13
FIGURE 7
1/4" MILD STEEL
6 1/2" SHEET WIDTH
25°c SHEET TEMPERATURE
60 CYCLE IMPEDANCE SHOWN SOLID
D.C. IMPEDANCE SHOWN DOTTED
SHUNT IMPEDANCE IN MICROHMS
18" SHUNT DISTANCE
12" SHUNT DISTANCE
8" SHUNT DISTANCE
4 SHUNT DISTANCE
SHUNT CURRENT IN HUNDRED OF AMPERES

Fig. 7

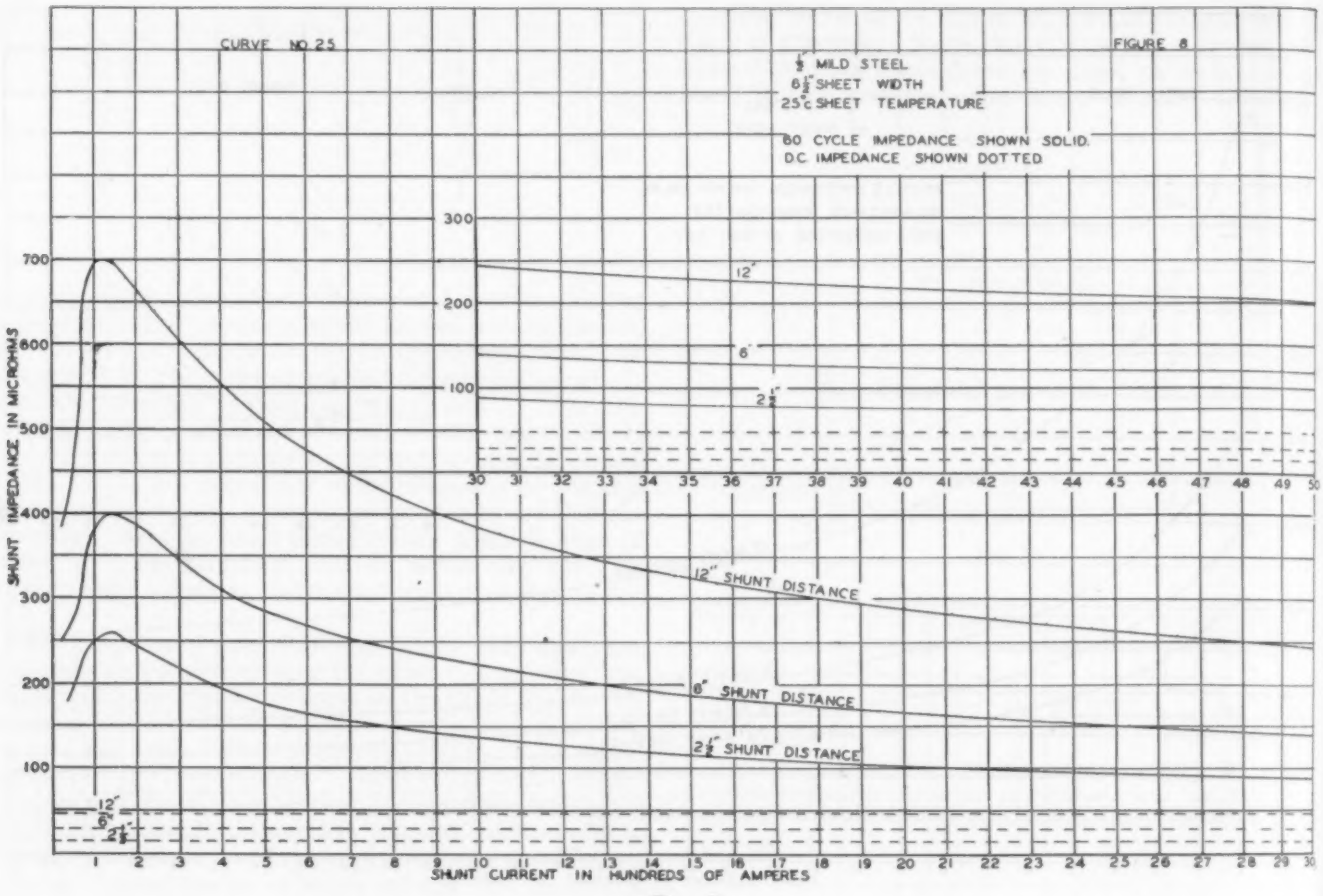


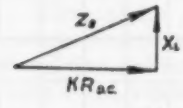
Fig. 8

Typical examples of these curves are shown in Figs. 5, 6, 7 and 8.

Figure 5 is a single impedance-shunt current curve for $^1/_4$- x 3-in. stock taken at 16 in. distance. This variation in impedance is due to the variation in the reactive component as the permeability of the steel in the shunt path changes. A slight amount of shunt current rapidly raises the permeability and impedance to a maximum and as the shunt current increases, the impedance decreases as the lowered permeability affects the reactive component. The impedance approaches a value equal to $KR_{d.c.}$ where K is the 60-cycle skin effect factor of the shunt circuit if it were nonmagnetic (permeability unity) and $R_{d.c.}$ is the d.-c. resistance of the shunt circuit. However, it is practically impossible to drive the permeability of the steel to unity and for this reason, the shunt impedance under the highest practical currents will be something greater than the $KR_{d.c.}$ value.

The shunt circuit is analogous to an iron core reactor having a very great number of one-turn coils in parallel. The steel fibers along the faying surface are represented by the shorter turns next to the iron core, which due to their shorter length, will have a tendency to carry an unequal portion of the load current. In the shunt circuit the flux and current carrying elements being one and the same, the shorter fibers along the faying surface in taking an over portion of the shunt current, create a permeability gradient through the sheet which produces a very significant skin effect much greater than found in a nonmagnetic shunt path.

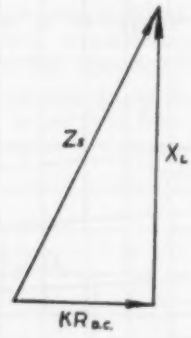
Figures 6, 7 and 8 are typical shunt impedance-shunt current curves. Stock thicknesses were $^1/_2$, $^1/_4$ and $^1/_8$ in. and sheet width in all cases was $6^1/_2$ in. For stock thicknesses in this range, it is seen that shunt impedance



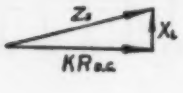
Z_0 = 60-cycle shunt impedance under very low shunt current

$R_{d.c.}$ = d.-c. shunt impedance

$K > 1$



Shunt impedance at a maximum Shunt current 100–200 amp.



Shunt impedance under very high shunt current

Fig. 9

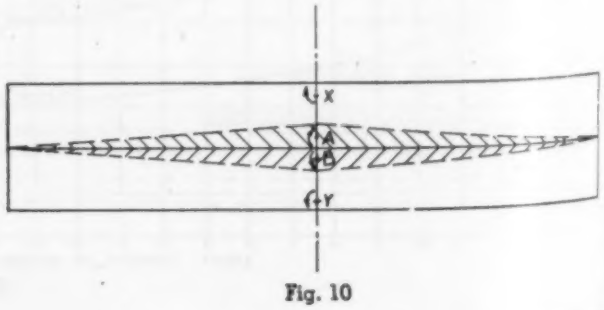


Fig. 10

varies only 2 or 3% from one stock thickness to another, or is practically independent of stock thicknesses.

As to what happens in the shunt circuit, consider current elements and directions as shown in Figure 10. The effective shunt voltage sees a shunt impedance of variable inductive reactance and 60 cycle resistance. The shorter path along the faying surface and the common skin effect of adjacent conductors causes the current to start a concentration along the faying surface. This incipient current concentration immediately aggravates itself by causing a flux saturation to start at the faying surface and drive the reactive component downward in this region producing a decided current concentration area. Stray flux from elements A and B tends to help saturate the faying surface steel in the other sheet by acting additively. This skin effect is such as to make the shunt impedances in $^1/_2$-, $^1/_4$- and $^1/_8$-in. sheets of equal widths and shunt distances look practically alike. At 3000-amp. shunt current, the impedance at 4-in. shunt distance in $6^1/_2$-in. width sheet for $^1/_8$-in. stock is 117 microhms; for $^1/_4$-in. stock, 115 microhms; and for $^1/_2$-in. stock, 112 microhms. This 2 or 3% reduction in impedance as sheet thickness increases can be attributed in part to the lowering of the impedance of the nugget section as its area increases.

Elements x and y in Fig. 10 do carry some current in parallel with A and B. The greater number of these remote low-current elements in $^1/_2$-in. stock over the number in $^1/_8$-in. stock would seemingly make the shunt path in $^1/_2$-in. stock look more conductive. However, it must be remembered that the additional steel in the $^1/_2$-in. stock makes the circuit more reactive to compensate for the reduction in resistance affected by the greater stock thickness. Test results indicate that this compensating effect is remarkably well balanced over the range of voltages used in welding.

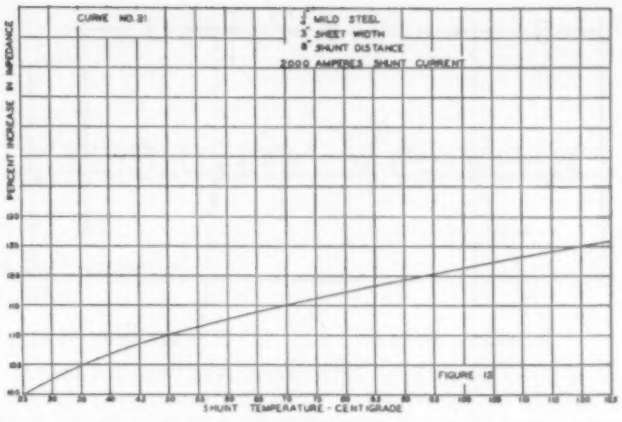


Fig. 12

Stock Thickness, In.	Sheet Width	$\frac{Z_{A.C.}}{Z_{D.C.}}$ (60 cycles)
$^1/_8$	3	1.32
$^1/_8$	$6^1/_2$	1.77
$^1/_8$	10	2.06
$^1/_4$	3	2.29
$^1/_4$	$6^1/_2$	3.35
$^1/_4$	10	3.95
$^1/_2$	3	4.25
$^1/_2$	$6^1/_2$	6.50
$^1/_2$	10	7.95

Shunt current = 2000 amp. Shunt distance = 6 in.

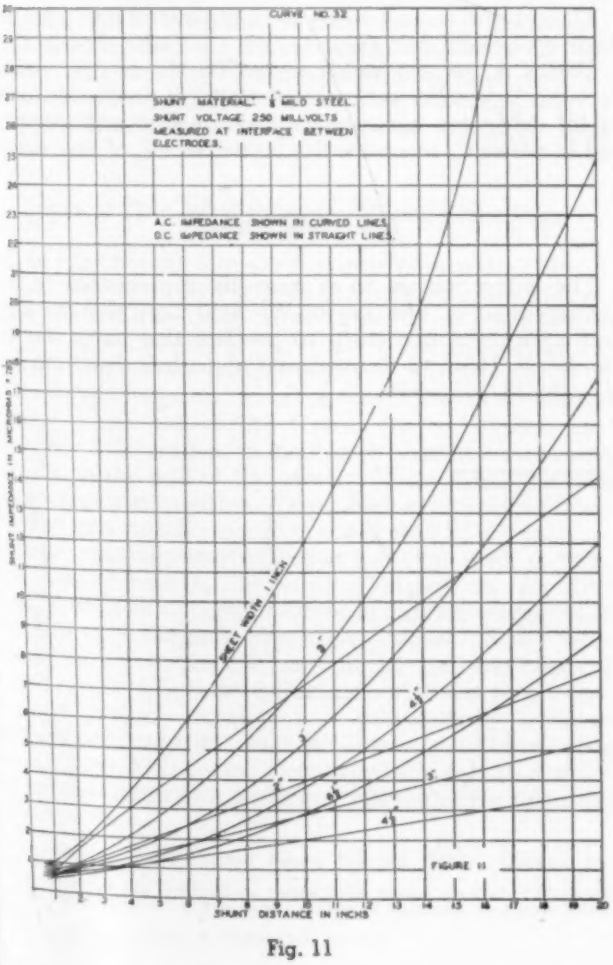

CURVE NO. 32
SHUNT MATERIAL: 6 MILD STEEL
SHUNT VOLTAGE 250 MILLIVOLTS
MEASURED AT INTERFACE BETWEEN ELECTRODES.
A.C. IMPEDANCE SHOWN IN CURVED LINES.
D.C. IMPEDANCE SHOWN IN STRAIGHT LINES.
SHUNT IMPEDANCE IN MICROHMS X 10
SHEET WIDTH - INCH
FIGURE 11
SHUNT DISTANCE IN INCHS

Fig. 11

The above table shows a ratio of 60-cycle shunt impedance to d.-c. shunt impedance for a given shunt current and spot spacing. For lower currents the ratios increase considerably and for greater currents the ratios decrease to a lesser extent. The ratios indicate the rapidity with which the d.-c. shunt impedance decreases as stock thickness increases, whereas the 60-cycle impedance remains practically constant for the subject range of sheet thickness.

The data for Fig. 11 was taken under a different setup to include the current concentration impedance around the electrode. A weld of Class B was again placed near the end of the sheets and $^1/_{32}$-in. mica sheet placed between the sheets so that all transformer current became shunt current. Instead of using drive screws for potential points, shunt voltage was measured from two strips of 0.010-in. copper strip placed on both sides of the mica directly between the electrodes and insulated from the steel except for an area at the end of the strip equal to the area and diameter of the electrode contact surface. The shunt circuit was again water cooled and the voltage on the copper strip terminals was held constant at 250 millivolts.

Figure 11 shows the a.-c. and d.-c. shunt impedances for various sheet widths and shunt distances. Note how the a.-c. shunt impedance always remains considerably higher than the d.-c. impedance and the rapidity with which the a.-c. impedance increases at increased shunt distances and reduced currents where the reactive component becomes very significant.

Total shunt impedance can be determined from sample curves shown in Figs. 6, 7 and 8 by compensating for one additional current concentration region.

Three tested methods can be used to artificially increase the a.-c. shunt impedance: (1) by use of "clappers"; (2) by keeping the shunt circuit outside the welder

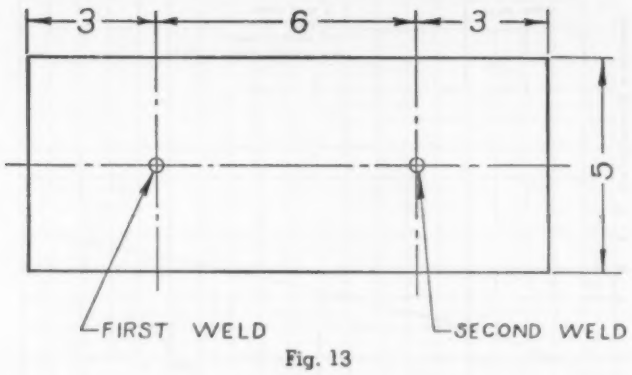


Fig. 13

throat; and (3) by taking advantage of heat in the weld stock produced by previous welds.

"Clappers" amount to external additions of steel to the shunt circuit and so named from the way they clap into place over the shunt circuit when the first surge of shunt current begins to flow. "Clappers," $^1/_4$ x 3 x 8 in., held to the electrodes by means of cantilever springs so that they rested approximately an inch away from the weld sheets, were quickly drawn into contact with the shunt path and reduced the shunt current by amounts proportional to the effective shunt voltage. As soon as current flow ceased, the clappers drop back into rest positions clear of the weld sheet.

A second method to affect an increased shunt impedance amounts to moving the weld stock from the throat outwardly as the spot pattern is followed instead of into the throat. The throat field helps saturate the steel in the shunt path reducing the reactive component of the shunt impedance. This effect is more pronounced, the heavier the sheet stock and the greater the throat current. For $^1/_4$- x 3-in. stock and only 2000 amp. throat current, the shunt impedance outside the throat was 21% above the shunt impedance when the shunt circuit was in the welder throat.

Figure 12 indicates how shunt impedance changes as the temperature of the sheet changes. From this it can be seen that in production it is better from a kva. demand and weld consistency standpoint (considering no correction in the voltage for shunt current) to follow a spot pattern as rapidly as possible going from one weld to next nearest weld.

As a test check on the foregoing measurements, a group of 48 shunt welds was made in $^1/_4$-in. sheet, 5 in. in width. This stock was certified as X-1020 (Fig. 13). Sheets were 12 in. in length.

Stock was pickled and wheel brushed and the surface maintained as uniformly as possible. All machine settings were held constant for the entire 96 welds and welding was done at a time when there was little outside disturbance on power and water supplies. All welds, both first and second, were made with the stock cooled to room temperature.

This group of welds was divided into three series:

Series A. The shunt circuit outside the throat, that is, 9 in. of the sheet was outside the throat and 3 in. inside. First welds were made with the stock in this same position to maintain the same amount of steel in the same proximity of the throat for all welds.

Series B. Same as Series A except $^1/_4$- x 5-in. wide clappers were used over the shunt circuit. All first welds were made with the clappers in position for the same reason as given above.

Series C. The shunt circuit was in the throat, that is, 9 in. of the sheet was held in the throat for both first and second welds and 3 in. outside.

Not knowing how much effect manipulation of the shunt current would make on these welds, it was decided to use a weld schedule where variation of shunt current would have some readily notable effect on shear strength. The machine settings were arranged to give the same Class B weld schedule used in Fig. 1 where the average single spot shear strength was 17,570 lb. The current was slightly reduced from this schedule where the single spot shear strengths fell between 15,000 and 16,000 lb. which gave assurance that the current-strength characteristic was not flat for this current level. Although the slope of the current-strength curve was not known for this point of operation, it definitely is in the range of practicality and could very easily be the operating point with the original 17,570-lb. shear-strength schedule where some of the current was being by-passed to one or more shunt welds.

All first and second welds were separated into separate shear specimens and shear tested. Results showed that in Series A, second welds tested 65.1% of first welds; in Series B, second welds tested 100% of first welds (only 16 lb. difference between average of first and second); and in Series C, second welds tested 48.7% of first welds.

Acknowledgment

The writer wishes to express his appreciation to the Management of The Taylor-Winfield Corp. for the time and equipment necessary to prepare this paper and to Dr. W. F. Hess, of Rensselaer Polytechnic Institute, for his valuable criticism.

Integral Bosses for Pressure Vessels*

By H. L. Anthony and H. P. Schane†

Introduction

THIN-WALL pressure vessels are fabricated in large quantities: some according to pressure vessel codes, others to noncode construction. In the thin-wall pressure vessel field, openings for pipe connections are important in the design and construction of these vessels whether the openings or bosses are attached in the head or the shell. Through these openings liquids and gases flow under pressure to points of use. In many cases severe mechanical abuse is given to the connectors during initial installation and subsequent life of the vessel. Fatigue, vibrational stresses and corrosion are conditions under which bosses are required to operate in service.

In designing bosses for thin-wall, unfired pressure vessel service according to the A.S.M.E. Code, it is not necessary to reinforce openings in the vessel wall where the opening does not exceed 2 in. in diameter.[1] The use of such bosses, having openings of 2 in. and less in diameter, is extensive in the thin-wall pressure vessel industry, and it has been estimated that over twenty million bosses of this class are used annually. It is this class of integral boss that will be described in this paper. The integral boss can be made in all sizes from the $^1/_8$- to the $1^1/_2$-in. pipe-tap diameter having thread depth sufficient to comply with code[2] specifications. In sketch form, Fig. 1 gives the dimensions of these bosses for A.S.M.E. Code requirements.

Types of Thin-Wall Pressure Vessel Openings

Generally, the openings or bosses in thin-wall pressure vessels are attached by one of the following procedures: (1) by manually welding, either by arc or by gas, a forged or cast boss to the wall of the vessel where an opening has been provided for such a connector; (2) by projection or resistance welding a machined or coined boss in a punched opening in the wall of the vessel; (3) by pressing mechanically a forging or a machined boss in an opening provided in the wall of the vessel; (4) by brazing a boss or a connector with either low- or high-temperature brazing alloy in a suitable opening in the wall of a vessel.

Where manually welded bosses are employed on thin-wall pressure vessels, the welding rate on an incentive basis becomes an important factor in cost and is generally conceded to be the most expensive process. Some processes of welding bosses manually in the shell and heads of vessels require a bare-wire electrode with the result that excessive porosity develops and subsequently leads to high and costly repairs; such processes apply to noncode tanks. Even with coated electrodes on single pass welding the opportunity for leaks generally depends upon the human factor.

Projection and resistance welding of bosses can be accomplished economically after the purchase of expensive electrical equipment. In most cases such equipment can only be justified on the power-cost basis where the energy demand of these machines does not exceed the normal peak for other necessary electrical equipment. Resistance-welding machines of this type are usually designed specifically for one or two sizes of bosses and lack flexibility on sizes and shapes. Although the resistance welding of bosses is exceedingly rapid, care and maintenance of the dies and equipment are essential for long production runs without leaks. Bosses attached by the resistance welding process have not been accepted for the construction of vessels under national codes.

Pressed bosses have been used to some extent by various manufacturers in range boiler construction primarily for the side-arm heater and thermostat bosses. This type of boss is cold-pressed in punched openings. The operation is rapid, but the final attached boss has a number of inherent disadvantages, namely (1) a loose boss can easily develop if good punch edges are not maintained for pressing, (2) in making pipe connections to this type of boss, often high torque loads applied by a wrench will cause the pressed boss to leak, (3) during curling and

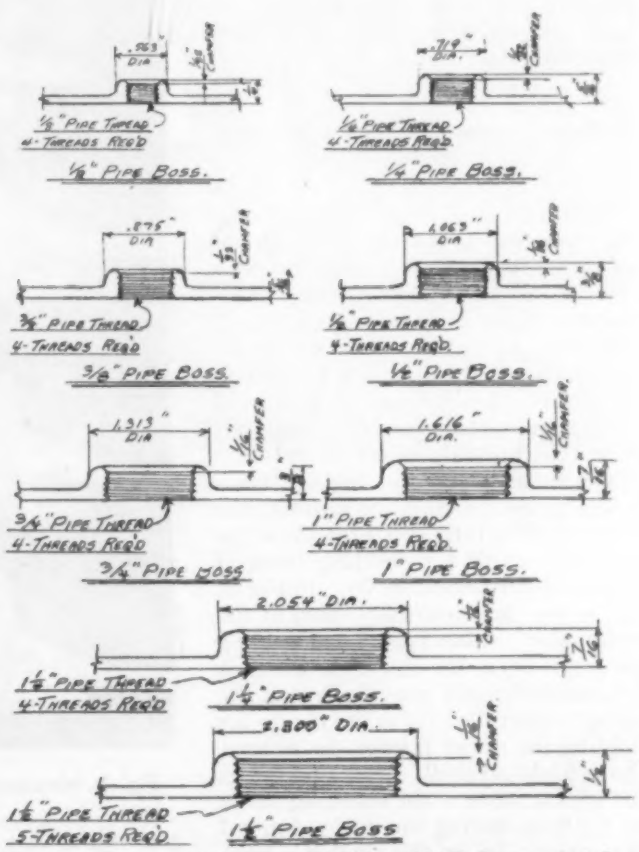


Fig. 1—Dimensional Requirements for A.S.M.E. Bosses, $1^1/_2$ In. and Less in Diameter

* Scheduled for Twenty-Eighth Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 19, 1947.

† Senior Fellow and Technician, respectively of the multiple Fellowship sustained by the Scaife Co. at Mellon Institute of Industrial Research, Pittsburgh, Pa.

[1] Paragraph U-59, A.S.M.E. Code, 1943 Edition.

[2] A.S.M.E.-A.P.I.

coining of the pressed boss, cracks may develop in the skirt of the boss that may lead to subsequent leaks and (4) where a pressed boss is found to leak, it is generally repaired by welding the complete circumference.

Both low- and high-temperature brazing alloys are used to attach bosses to the wall of pressure vessels. For small containers the process has worked out satisfactorily on such vessels as insecticide bombs or filter reservoirs, but for larger vessels welding processes are generally preferred over brazing.

With the integral boss many of the previously mentioned individual disadvantages are eliminated since the boss becomes a sound integral part of the vessel itself.

Several sections of the common type A.S.M.E. bosses, which are used in the thin-wall vessel industry, are shown in Fig. 2. Three types of pressed metal bosses are exhibited in Fig. 3. The upper section in this figure represents the best in this class of boss; the most undesirable type of pressed boss is shown at the bottom of the figure.

The Integral Boss

Typical integral bosses are displayed in Fig. 4 as companionate sets of $^3/_8$- and $1^1/_2$-in. sizes in the as-polished and in the as-etched condition. Bosses of this type eliminate the notch effect from the root and face of welds by being an integral part of the vessel wall. In the A.S.M.E. Code for unfired pressure vessel requirements, it is only necessary to have four full threads for the $^3/_8$-in. and five full threads for the $1^1/_2$-in. boss. These bosses fully meet these requirements.

A New Process of Casting Integral Bosses

Research here has demonstrated that integral bosses can be made on all thicknesses of plate without difficulty up to and including the $1^1/_2$-in. size boss. On sheet it has been found that No. 18-gage is the minimum thickness on which integral bosses can be made. A sectional elevation of the equipment that has been employed to make integral bosses on pressure vessel shells is given in Fig. 5. Here is illustrated a section through the flux head and the boss dies that show the essential setup for welding integral bosses on cylindrical shells. In Fig. 5, (*a*) is the flux normally used in the automatic submerged arc-welding process; (*b*) is the electrode which is fed concentrically into the hole of the upper copper die; (*c*) is the clamp for holding the upper copper die against the cylindrical shell; (*d*) is the copper die which imparts the resulting shape to the boss during the cycle of metal deposition; (*e*) is the shell of a pressure vessel clamped and supported on the copper back-up die (*g*); (*f*) is the female copper back-up die which surrounds the copper back-up die (*g*) and provides a water cooling area (*l*); the nut (*h*) locks the welding electrode ground to the copper back-up die (*g*); (*j*) shows the integral boss being cast with the molten flux (*k*) on the top of the integral boss and contained in the copper die (*d*). An actual photograph of welding being done on this fixture is shown in Fig. 6.

Features of the New Process

Either new flux or reground used flux can be utilized in the welding of integral bosses. It has been found that

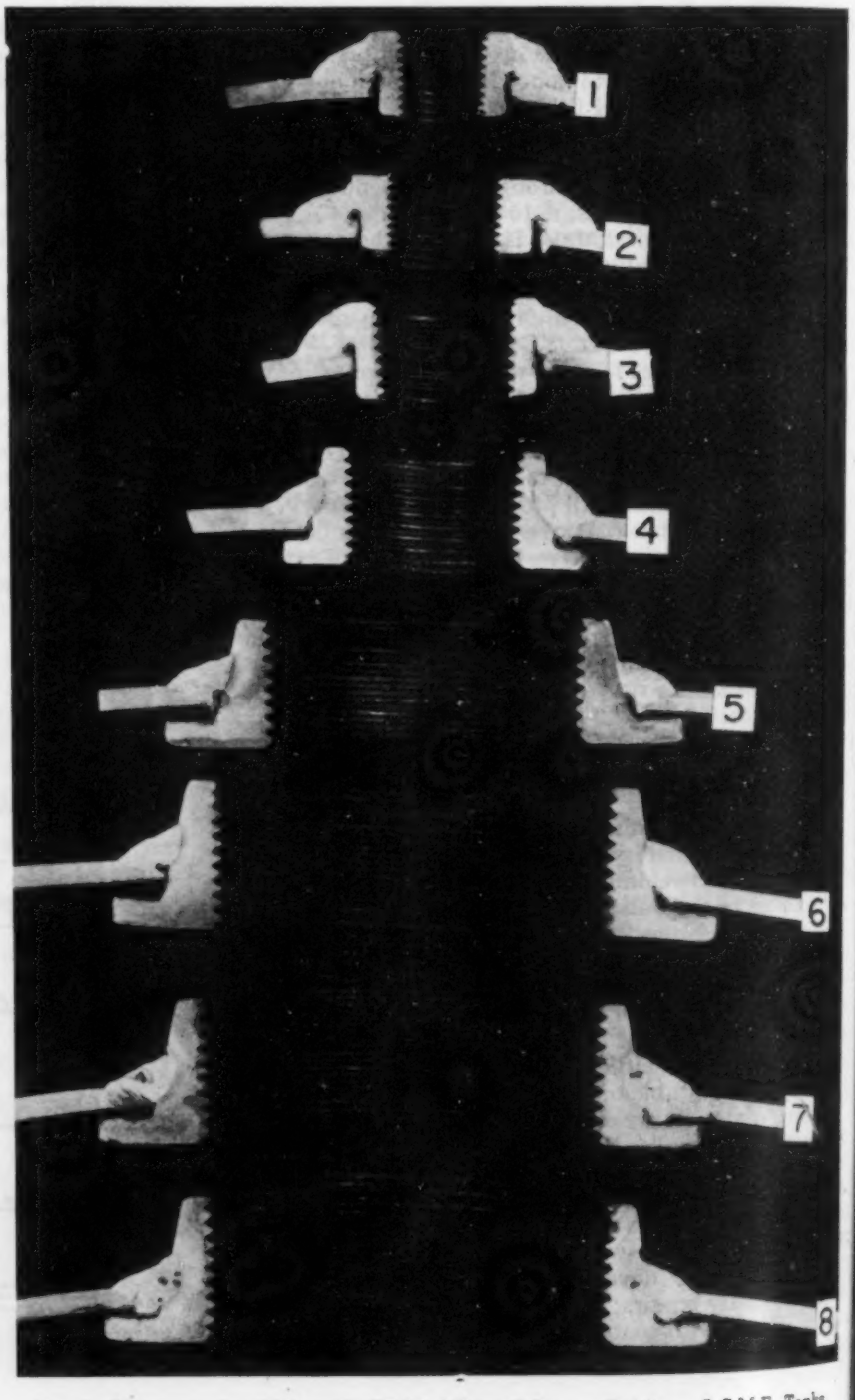


Fig. 2—Macrographs of Manually Welded Forged Bosses Cut from A.S.M.E. Tanks

No. 1, $^3/_8$-in. forged boss with notch effect; No. 2, $^1/_2$-in. forged boss with notch effect; No. 3, $^3/_4$-in. forged boss with notch effect; No. 4, 1-in. forged boss with notch effect; No. 5, $1^1/_2$-in. forged boss with notch effect; No. 6, 2-in. forged boss with notch effect; No. 7, 2-in. forged boss with porosity; No. 8, 2-in. forged boss with porosity.

Fig. 3—Mechanical Bosses, Commonly Called Pressed Bosses, Employed in the Construction of Range Boilers and Heater Shells, Etched to Show Mechanical or Frictional Fit to the Shell of the Boiler. 3% Nital. × 3

Table 1—Welding Data Chart for Integral Steel Bosses

Boss Pipe Size, In.	Boss O.D. In.	Over-All Height Including Plate Thickness, In.	Weld Time, Sec.	Handling Time, Sec.	Electrode Diameter, In.	Volts	Amp.	Weight of Electrode per Boss, Lb.	Weight of Flux per Boss, Lb.	Type Flux
1/8	0.563	1/4	5	30	3/16	30	490	0.011	0.011	L-660 through 60-mesh
1/4	0.719	5/16	9	30	3/16	30	490	0.019	0.019	L-660 through 60-mesh
3/8	0.875	5/16	16	30	3/16	30	490	0.036	0.036	L-660 through 60-mesh
1/2	1.063	3/8	16	30	5/16	38	640	0.056	0.065	L-660 through 60-mesh
3/4	1.313	3/8	21	30	3/16	38	640	0.096	0.130	L-660 through 60-mesh
1	1.660	7/16	30	30	3/16	38	640	0.189	0.261	L-660 through 60-mesh
1 1/4	2.054	7/16	35	30	3/16	40	740	0.280	0.392	L-660 through 60-mesh
1 1/2	2.300	1/2	50	30	3/16	40	740	0.426	0.596	L-660 through 60-mesh

reground used flux works adequately in the welding of integral bosses, especially if it has been ground to pass 60-mesh. By having a finely ground flux, bubbling and surging of the flux are held to a minimum during the period of metal deposition.

Under all circumstances it has been found advisable to use a copper water-cooled back-up die on material 3/16-in. and under in thickness because a large quantity of heat is concentrated within a small area. About 2 gal. of circulating water per minute were used to weld the 1 1/2-in. integral boss. If a large number of bosses is to be made in a sequence of continuous operations, it has been found advantageous to have the upper copper die water cooled.

Table 1 gives the necessary data in welding integral bosses from 1/8- to 1 1/2-in. size using 3/16-in. electrode; for example, the 1/8-in. boss can be made in 5 sec. while the 1 1/2-in. boss can be completed in 50 sec. The welding time for other size bosses as well as the current and voltage are also given in Table 1. Other sizes of electrodes from 1/8- to 5/16-in. diameter can be used to weld integral bosses; with the smaller diameter electrode, the welding time is increased and conversely with 5/16-in. electrode the welding cycle is decreased. Primarily, for flexibility, the 3/16-in. diameter electrode can be used for 1/8- to 1 1/2-in. boss sizes.

The welding time on the 1 1/4- and 1 1/2-in. bosses can be reduced with the 5/16-in. electrode, provided the material and the copper die will dissipate the increased heat from higher amperage. As the boss diameter increases, it is necessary to raise the voltage in order to spread the deposit in the area of the upper copper die and at the same time increase the amperage for an increased rate of electrode deposition.

One of the unique facts surrounding this integral boss process is the formation of an envelope of flux around the boss during the deposition of metal. Not only does the flux remain *in situ* on top of the boss, but also a film of flux 1/64–1/32-in. chills on the face of the upper mold and totally encloses the boss. Upon removal of the flux the entire boss exhibits a surface appearance analogous to that of a submerged arc type of weld.

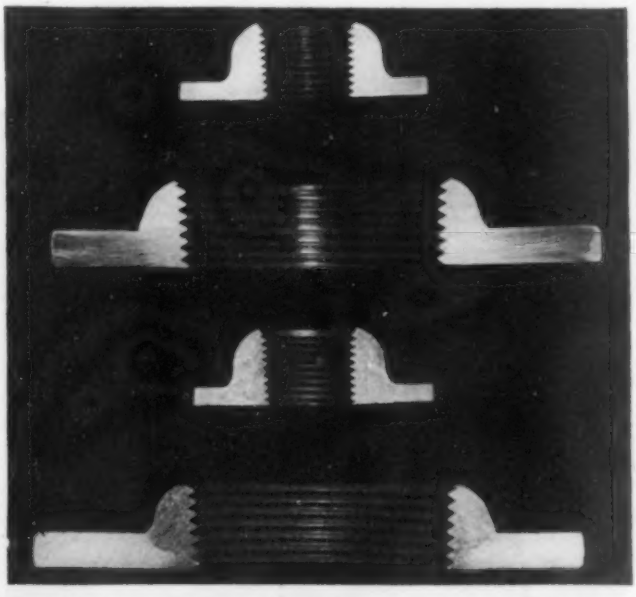


Fig. 4—Integral Bosses Taken from the Shell Wall of Two Vessels in the Longitudinal Direction. Upper Companionate Bosses As Polished; Lower Companionate Bosses Etched in 3% Nital. Magnification, full size

In designing the boss opening in the upper copper die 1/16 in. is allowed on the die diameter for the flux envelope that develops on the circumference of the mold in the welding cycle. The flux film is very consistent in thickness for bosses in the size of 1/8- to 1 1/2-in. and averages 1/32 in.

The deposited metal generally will assume the shape of the upper copper mold. A fillet of 1/16- to 1/4-in. radius can be machined on the lower circumference of the upper

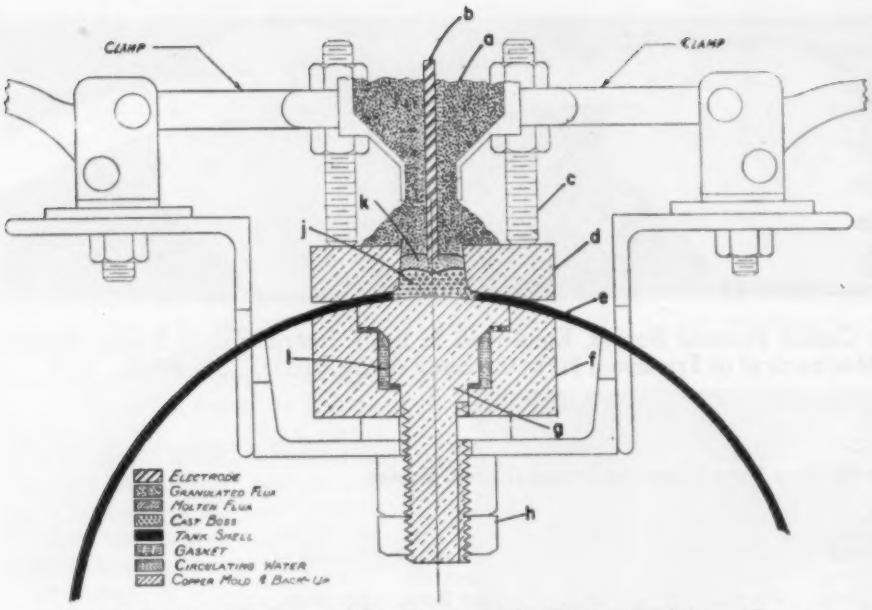


Fig. 5—Sectional Elevation of Die Equipment for Casting the Integral Boss on Cylindrical Surfaces

copper die so that the resulting boss will be provided with a fillet from the boss to the parent sheet or plate.

By retracting the electrode wire at the end of the welding cycle prior to cutting off the welding current, a dimple can be formed in the diametric axis of the boss for the purpose of subsequent cold or hot punching. A series of integral bosses, neither punched nor threaded, with flat die setups are shown in Fig. 7.

After the boss has been made an integral part of the vessel wall, the solid boss can be drilled out or punched. Either hot or cold punching of the solid boss has been found feasible prior to reaming and tapping. Because of metal drag during cold punching, it has been found advisable to use a punch approximately $^1/_8$ in. less in diameter than the drill size suitable for tapping. Following the punching operation the boss is reamed and tapped.

Integral bosses ranging from $^3/_8$ to $1^1/_2$ in. in size with attached nipples are shown in Fig. 8. Bosses welded by this process give the appearance of a streamlined connector without external and internal weld metal that normally accompanies this type of connector. Integral bosses with the nipples removed are illustrated in Fig. 9 after punching and tapping. The streamlined appearance of the boss is again displayed.

Commercial automatic welding electrodes were employed in making these bosses and in the as-welded, cold-punched condition the bosses were readily threaded after reaming by means of an interrupted tap.

A feature of the integral boss welded on the outside of the vessel is the drainage advantage it possesses over flanged, sleeve and peened bosses. This advantage is exemplified in the process of galvanizing certain types of pressure vessels where it saves on the average of one-half pound of zinc per vessel. Normally this half pound of

Fig. 6—Fixture for Welding Integral Bosses on Short-Length Cylindrical Shells

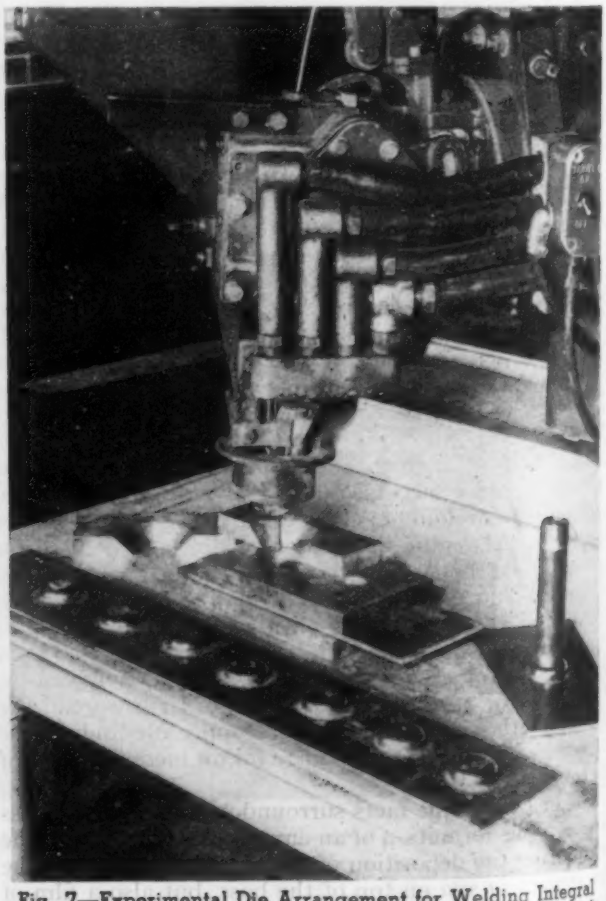


Fig. 7—Experimental Die Arrangement for Welding Integral Bosses on Flat Sheet, Showing Copper Dies, Welding Head and Resultant Bosses

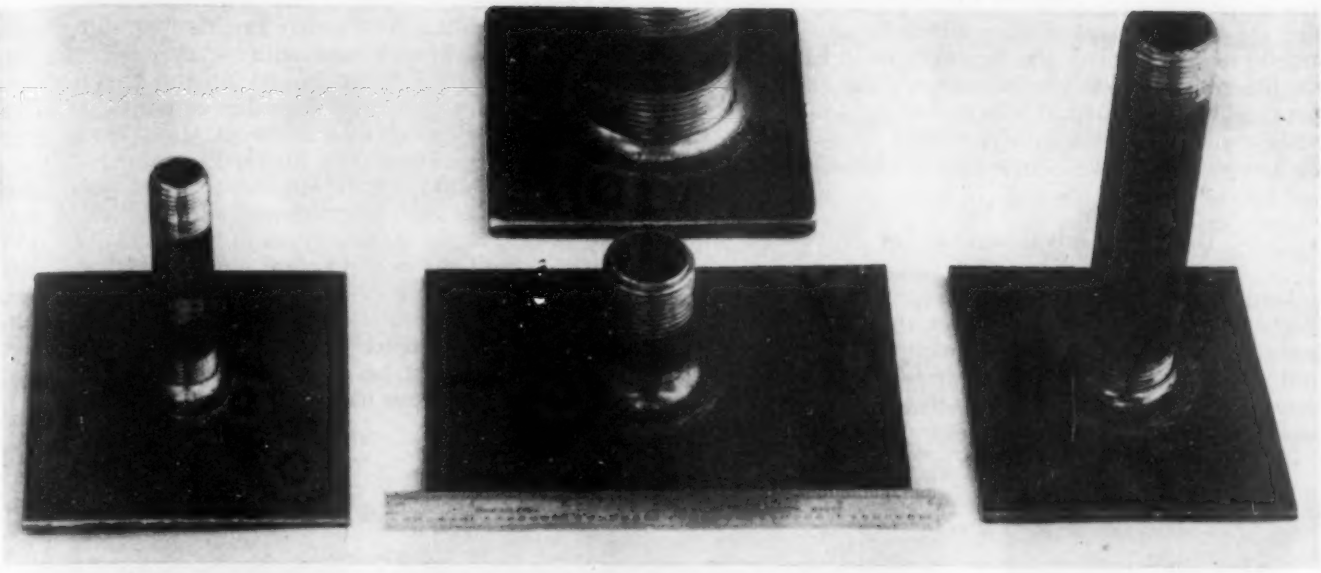


Fig. 8—A Group of Integral Bosses with Nipples Ranging from 1/4-In. to 1 1/2-In. Pipe-Tap Diameter

Center top, 1 1/2-in. boss; left, 1/4-in. boss; center, 3/4-in. boss; right, 1-in. boss.

zinc and possibly more is retained within the vessel because of flanged inside or peened bosses.

The series of bosses shown in Fig. 10 is displayed from the copper die back-up side or the internal surface of the pressure vessel. On plate thickness of 3/16 in., all sizes of integral bosses up to 1 1/2 in. can be made without remelting to any extent the interfacial contact metal against the copper back-up die. Where the gage thickness decreases to nine and less, the metal surface in contact with the copper back-up die melts when the arc is struck, but the molten metal is immediately solidified by the water-cooled copper back-up die. Examples of these conditions are also presented in Fig. 10. In the upper row, left, a 1/4-in. tapped boss has been welded directly through a No. 12 gage sheet. In the center of the same row are two unpunched 1-in. bosses on 3/16-in. plate. The same row, right, is a 1-in. boss on No. 12 gage sheet showing the extremities of actual metallic fusion. In the lower row of this figure at the left appears the copper back-up side of a 3/4-in. integral tapped boss on No. 14 gage sheet showing its area of fusion.

The largest size integral boss included in this paper is

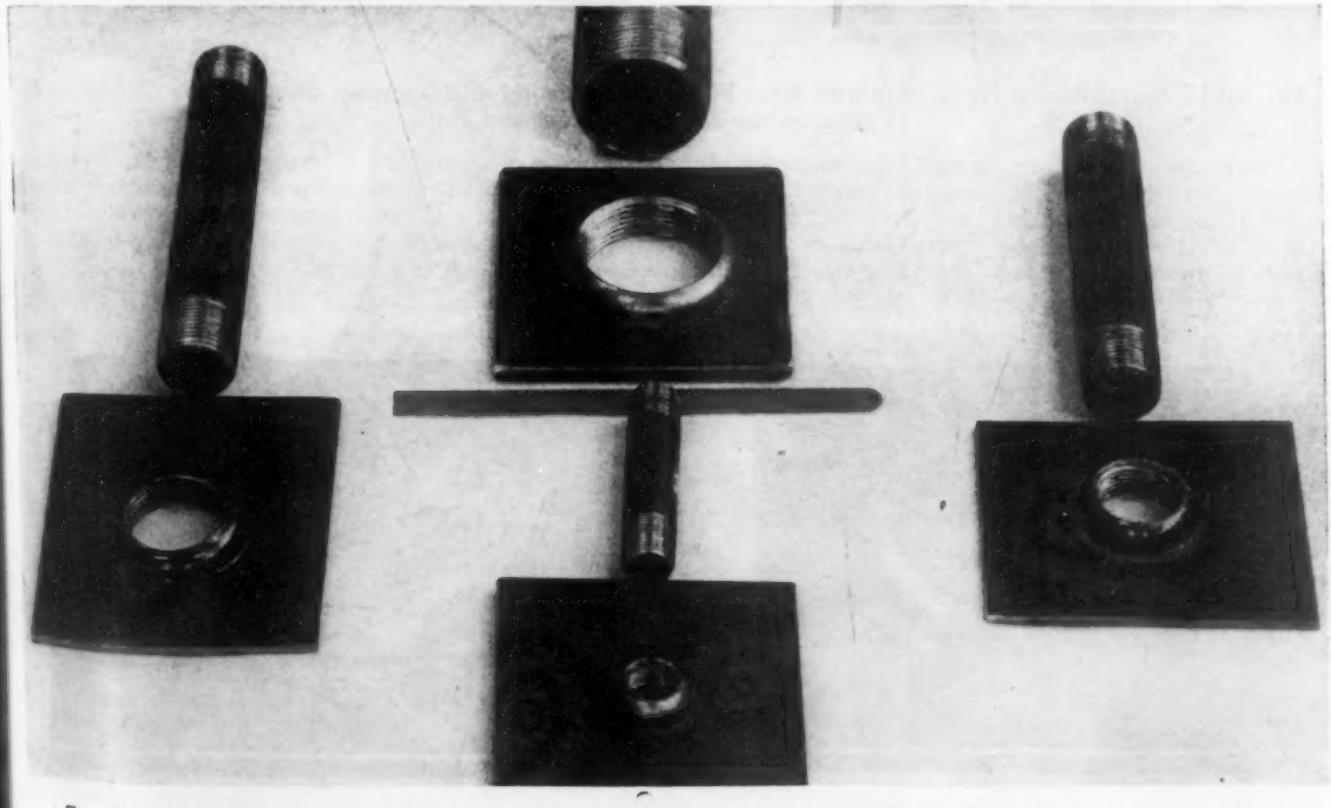


Fig. 9—Integral Bosses Ranging from 1/4-In. to 1 1/2-In. Threaded Pipe Tap without Screwed-In Nipples

Center top, 1 1/2-in.; left, 1-in.; right, 3/4-in.; center bottom, 1/4-in. bosses.

the $1^1/_2$-in. pipe-tapped boss which has an outside diameter of 2.3 in. This size boss appears in Fig. 11, where the integral boss is shown before punching and after tapping. The solid integral boss on the right illustrates the surface dimpling which is produced by retracting the electrode at the end of the period of welding.

Technical Advantages of the Process

Data included in this report are concerned only with steel bosses, but other metals can also be welded as integral bosses. Such metals as stainless steel, Everdur and Monel can be cast into bosses by this process. Samples of Monel bosses on No. 18 gage Monel sheet are shown in Fig. 12. At the left in this figure appears a $^3/_8$-in. integral Monel boss with a nipple connection, while on the right a $^1/_2$-in. Monel integral boss is shown solid. Stainless steel and Everdur can be cast in an analogous fashion, the variation in the process being chiefly the type of flux used for each metal.

Another advantage to be emphasized in this process is the soundness of the integral boss, especially where hundreds of thousands of these types of bosses are used each month in the light-wall pressure vessel industry. Such examples as propane cylinders, domestic range boilers, air receivers, pneumatic tanks, A.S.M.E. Code vessels, and containers constructed to other codes and where each tank or vessel must be physically inspected for leaks, sound, leak-free bosses have a considerable advantage.

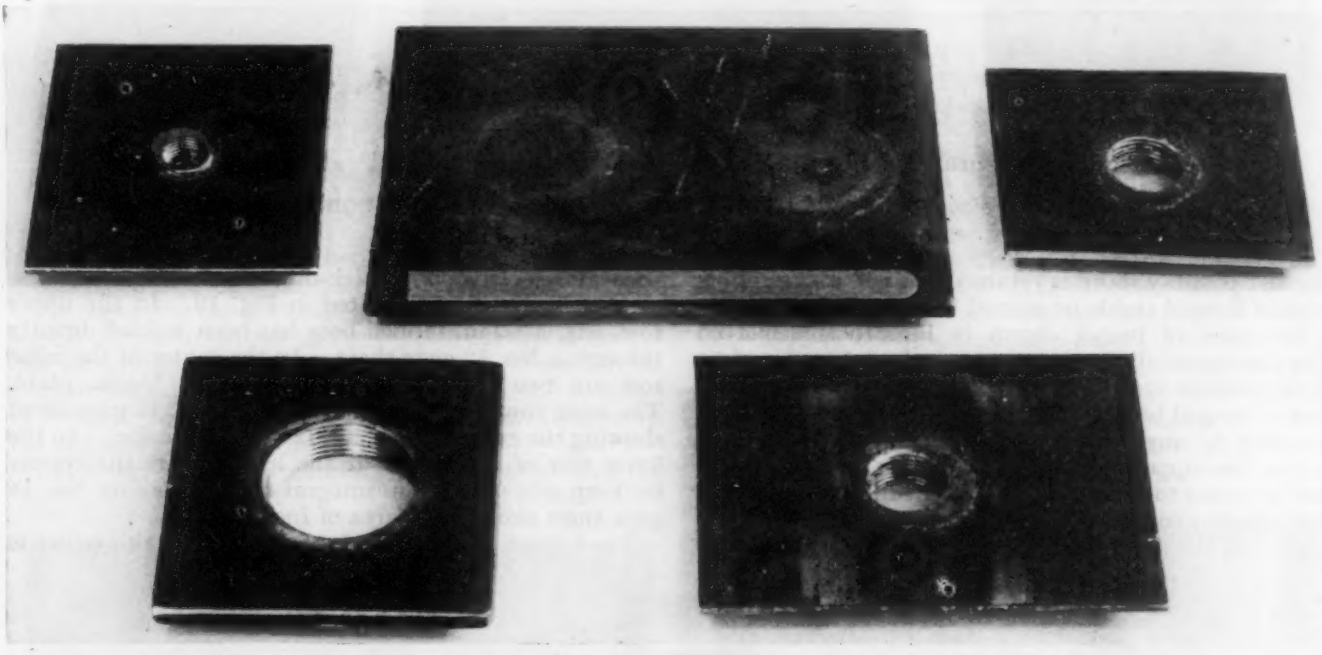


Fig. 10—Integral Bosses As Welded and After Punching, Reaming and Tapping, Showing the Condition of Fusion on the Bottom of Sheet and Plate

Upper row: Left, $^1/_4$-in. tapped boss as viewed from the inside diameter of a 12-gage pressure vessel shell. Center, two 1-in. diameter bosses as welded viewed from the inside diameter of a $^3/_{16}$-in. wall pressure vessel. Right, 1-in. diameter tapped boss as viewed from the inside diameter of a 12-gage pressure vessel shell. Lower row: Left, $1^1/_2$-in. diameter tapped boss as viewed from the inside diameter of a 7-gage pressure vessel shell. Right, $^3/_4$-in. diameter tapped boss as viewed from the inside diameter of a 14-gage pressure vessel shell.

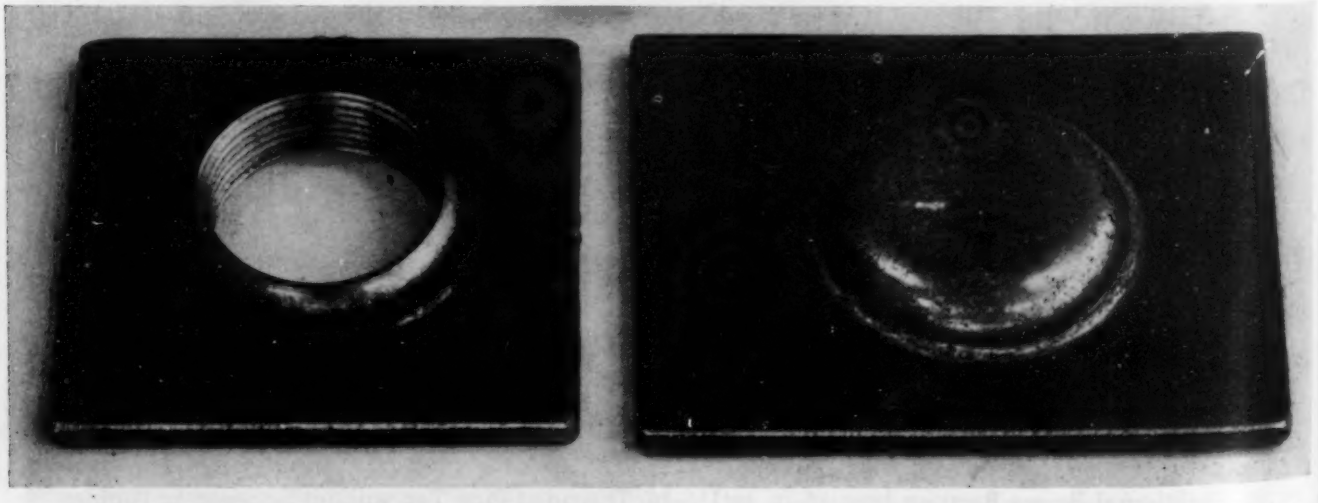


Fig. 11—$1^1/_2$-In. Pipe-Tapped Integral Boss on $^3/_{16}$-In. Plate Showing the Boss Prior to Punching, Reaming and Tapping

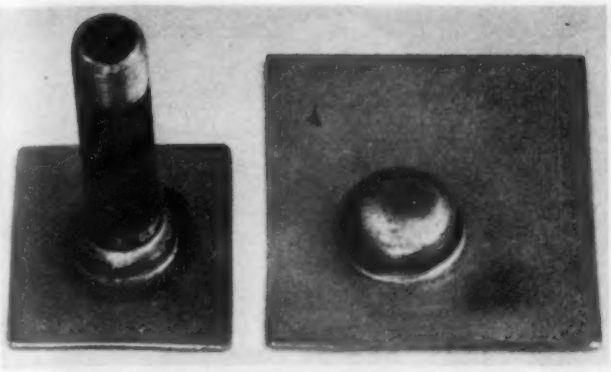
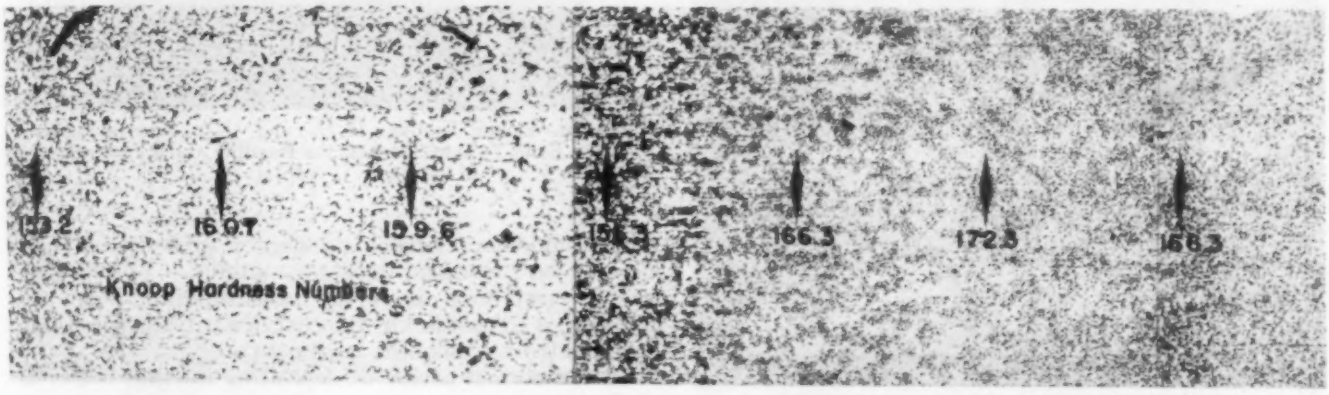


Fig. 12—$^1/_2$-In. Integral Monel Bosses Cast on 0.050-In. Monel

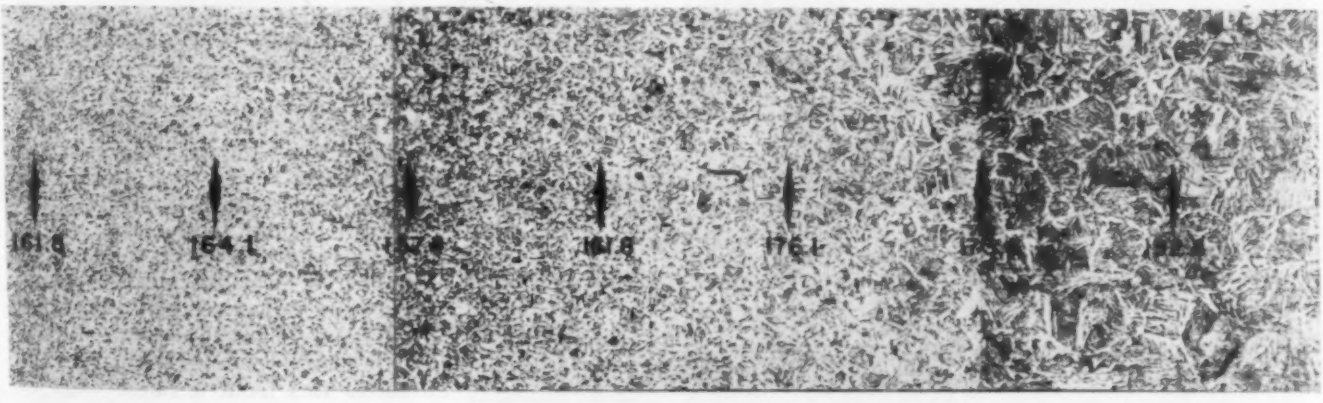
Left, $^1/_2$-in. tapped integral boss with nipple; right, $^1/_2$-in. boss.

Leak-free integral bosses have their advantage in galvanized vessels where boss leaks require extensive repairs and the regalvanizing of the vessel.

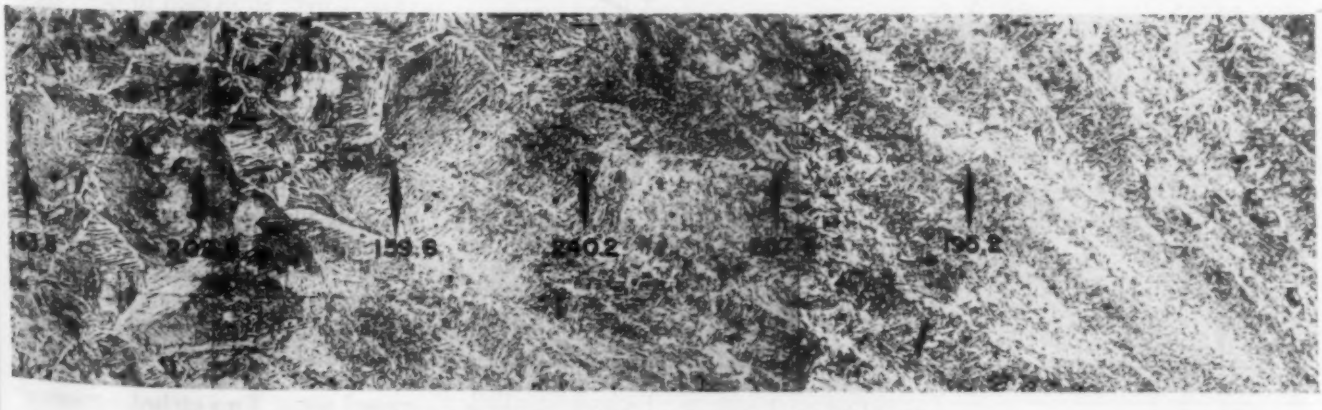
The soundness of the integral boss is demonstrated in Fig. 13. A group of etched sections is included in this figure. Starting from the top of the photograph the integral cast boss sizes are $^1/_4$, $^1/_2$, $^3/_4$, 1 and $1^1/_2$ in. on various plate and sheet thicknesses. Each section has been etched with 3% Nital to show the macrostructure of the integral boss and the extent of the fusion and heat-affected zone surrounding the parent plate and sheet material. Figure 13 also reveals the dimpled effect on the top of the integral boss which was mentioned previously in connection with the retraction of the electrode at the end of the welding cycle. Like other weld deposits of the same nature, the macrostructure is dendritic and each integral boss has its own fusion and heat-affected zone



A. Parent Metal Into the Transformation Zone



B. Transformation Zone Into the Grain Growth Area



C. Grain Growth Area Into the Weld Metal

Fig. 14—Photomicrographs in Panorama of an Integral Boss 1 In. in Diameter with Knoop Hardnesses as Indicated

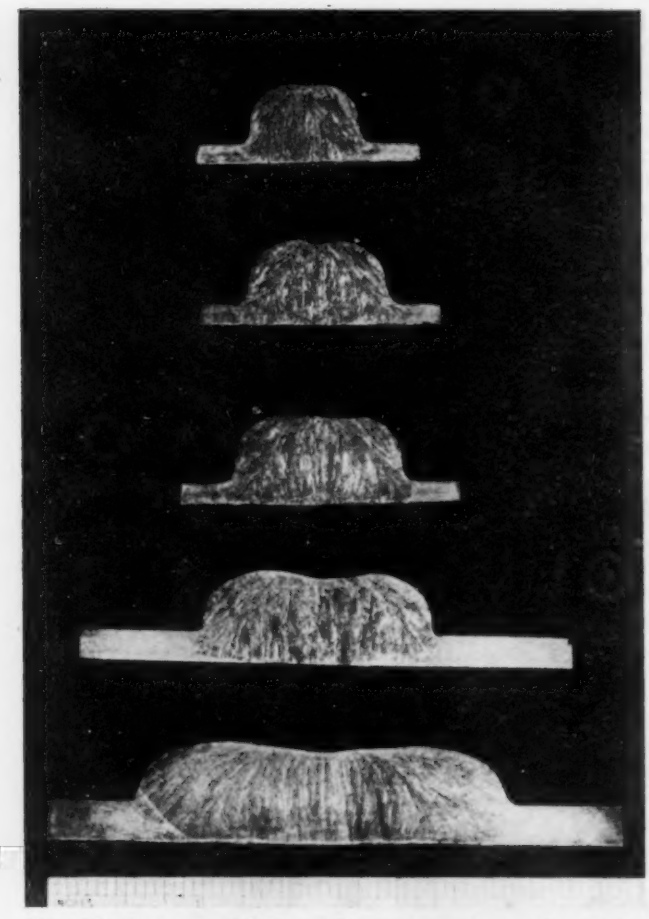


Fig. 13—Sections of Integral Bosses from the 1/4-In. to the 1 1/2-In. Pipe Tap Size Etched to Show the Structure and Soundness of the Bosses

Reading from the top down: 1/4-in. boss on 12 gage; 3/8-in. boss on 12 gage; 1/2 in. boss on 12 gage; 1-in. boss on 7 gage; 1 1/2-in. boss on 3 gage.

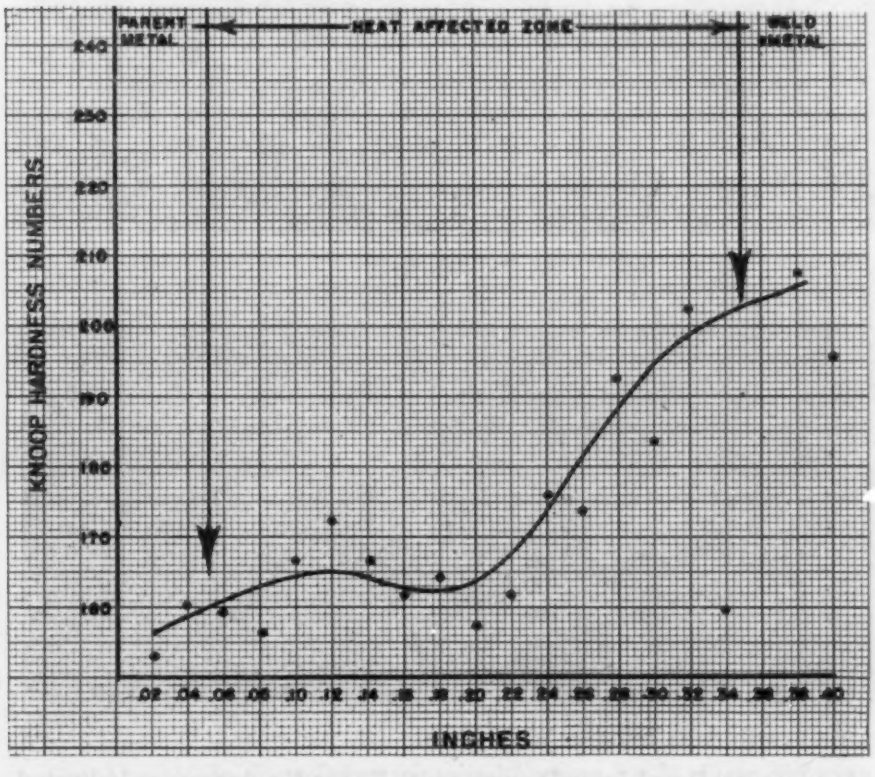


Fig. 15—Knoop Hardnesses of an Integral Boss from the Parent Metal to the Weld Metal

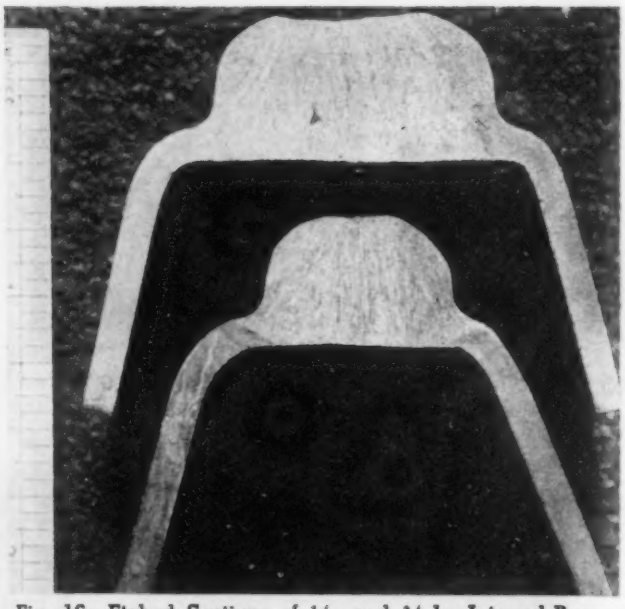


Fig. 16—Etched Sections of 1/8- and 3/8-In. Integral Bosses Given Bend Tests to Illustrate the Ductility at the Fusion Zone of the Boss. 3% Nital. × 2.

that would characterize a submerged arc weld if a linear deposit were made on the same material. By reheating the integral boss above its transformation point and allowing it to cool in air, the cast dendritic structure can be obviated by this heat treatment.

In the normal course of depositing integral bosses on shells of pressure vessels or on flat plates and sheets, very little if any distortion is noticeable in the parent metal Integral welding of bosses is somewhat different than normal linear welding in that the integral boss itself cools very slowly after the deposition cycle and shrinkage stresses are relieved by the thermal energy stored in the boss metal from welding.

A panorama of an integral boss photographed at 100 magnifications constitutes Fig. 14. Over these microscopic areas, from the parent metal to the boss metal, Knoop hardnesses have been taken at increments of 0.002 in. A hardness curve for this area is given in Fig. 15. The Knoop hardnesses in this area parallel approximately the resulting hardnesses from a linear weld on this same material.

Figure 16 shows two integral bosses which were subjected to bend tests, a method of determining qualitatively the interzonal ductility of the parent metal and the integral boss.

A considerable variation in section and shape can be obtained by this process of welding integral bosses. The integral boss cannot only be placed on the external area of a pressure vessel, but also on the inside wall of the vessel.

Integral bosses can be welded square, round or ellipsoidal in shape, but, in general, the round integral bosses are preferred for pressure vessel use. Two etched sections of integral bosses that are approximately one-half the distance through the vessel wall are shown in Fig. 17.

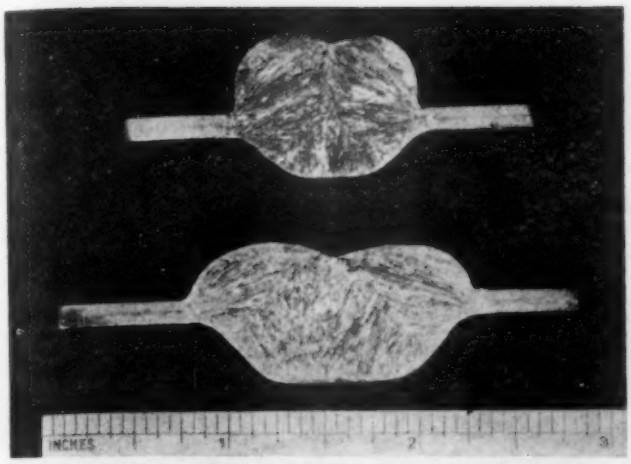


Fig. 17—Macrostructures of 1/4- and 3/8-In. Diameter Integral Bosses in Section Showing Some Producible Contours and Shapes. 3% Nital.

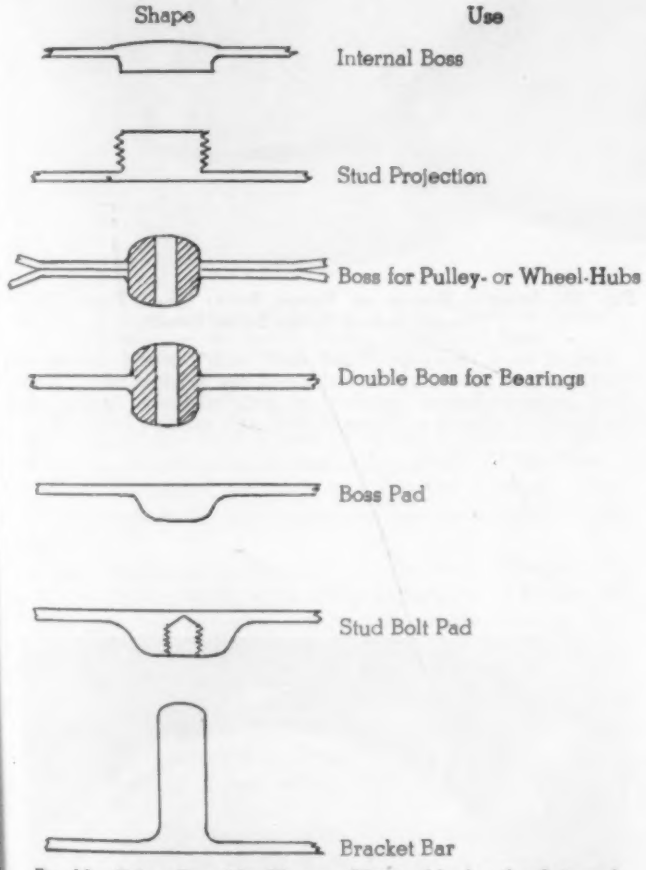


Fig. 18—Other Possible Shapes Obtainable by the Integral Boss Process

The method by which the integral boss is recessed is accomplished by changing the contour of the back-up die. A number of sectional variations can be obtained by this means if the design of the structure warrants the change from the normal outside integral boss.

Other possible sections which can be obtained by this method of welding are illustrated in Fig. 18. By having the proper amperage and current, a 3/16-in. diameter electrode can be made to weld an integral boss 3 in. in diameter for these sections.

It has been estimated in the thin-wall pressure vessel field that over twenty million bosses of 1 1/2 in. in pipe size, and less, are used annually in this type of container construction. In the domestic range boiler field alone three to four million of these bosses are used each year. By using this type of integral boss the inventory on sizes of bosses could be held within the limitations of electrode diameter at a considerable cost advantage.

The Process in Operation

An example of equipment used to weld integral bosses on range boiler shells is shown in Fig. 19. The equipment merely consists of an automatic submerged arc-type welding head and a fixture for the location of bosses and copper dies for metal deposition. In this figure a 1-in. integral boss is being welded on the shell of a No.

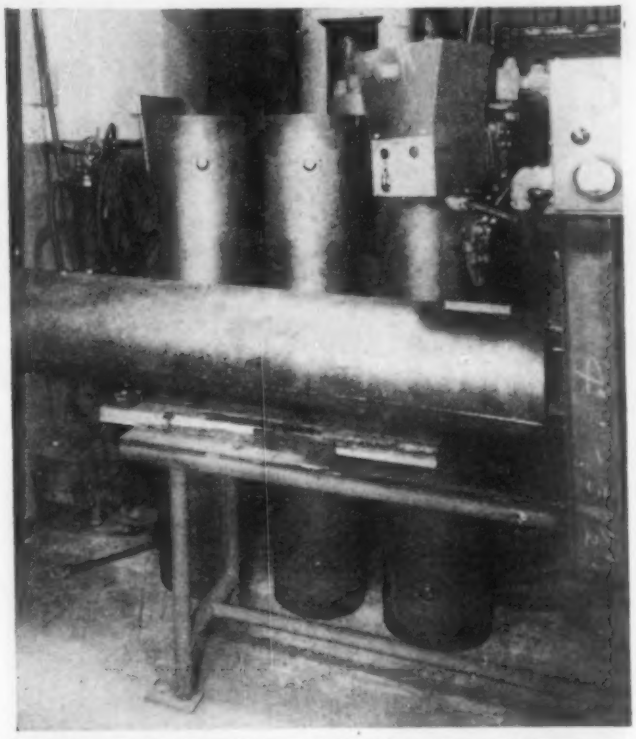


Fig. 19—A Machine Setup for Welding Integral Bosses on Range Boiler Shells Showing Welding Head and Upper Copper Die

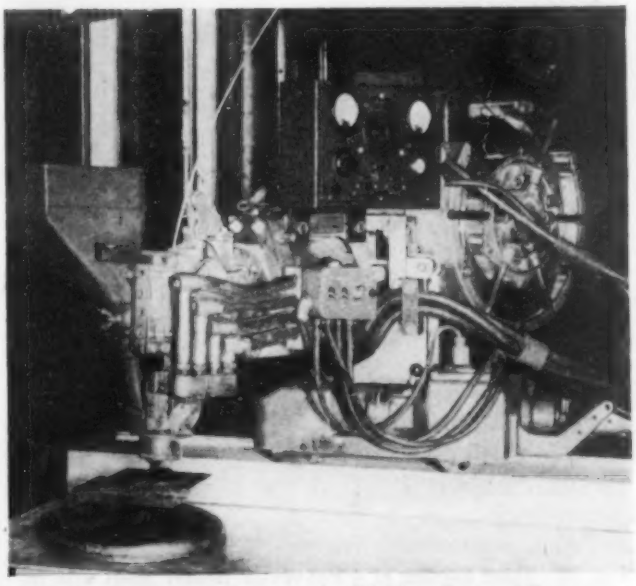


Fig. 21—Experimental Setup for Welding Integral Bosses on Saddled Dished Heads

Fig. 20—Integral Bosses on Range Boiler Shell Stock (No. 14 Gage) and on Range Boiler Heads

Center back, 14-gage rolled shell with integral bosses; left front, integral bosses on the outside of the saddled head; center front, integral bosses punched on saddled head; center right, inside fusion area of an integral boss on a saddled head.

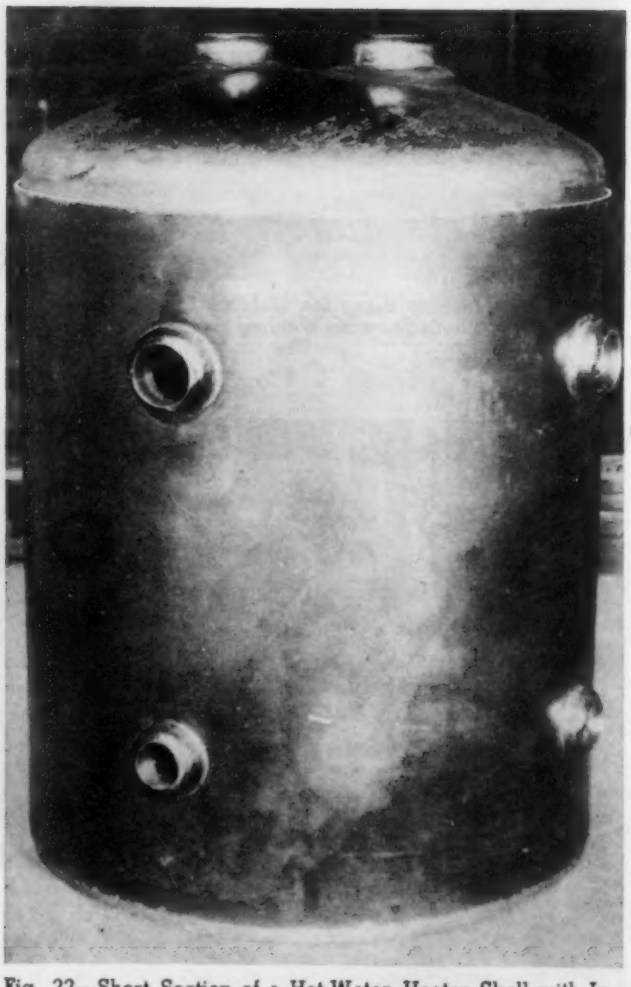


Fig. 22—Short Section of a Hot-Water Heater Shell with Integral Bosses Showing the Punched Bosses in the Head and Shell

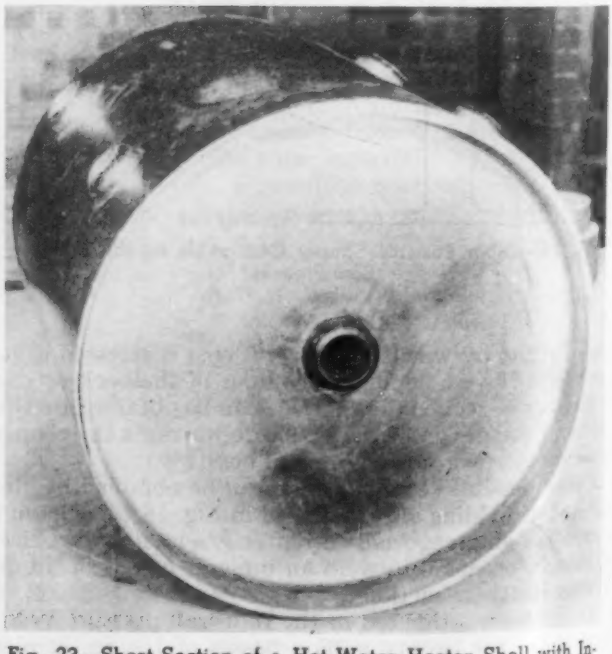


Fig. 23—Short Section of a Hot Water Heater Shell with Integral Bosses Showing the Punched Bosses in the Shell and Bottom

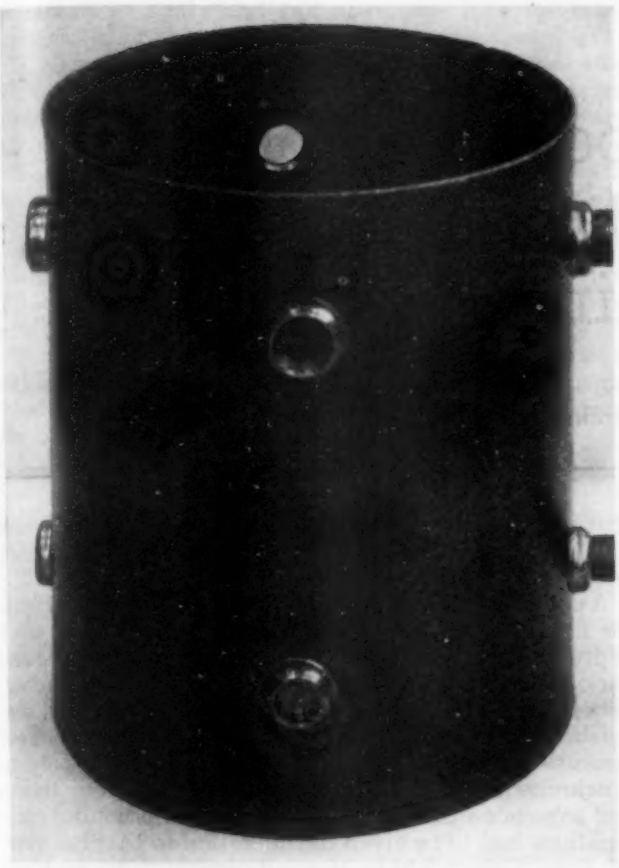


Fig. 24—Tapped Integral Bosses on a Shell Showing Profile of Bosses and the Inside Fusion of the Back Boss

14 gage domestic range boiler. The 1-in. size boss can be attached at the rate of one in 30 sec.; the only operation that is essential in the welding success of the boss is the effort necessary to push the starter button. Flux addition, time cycle, and clamping can be automatically controlled.

In the foreground of Fig. 20 is the ordinary designed 30-gal. range boiler head with integral bosses. On the left of this figure, the external appearance of the integral boss is shown; on the right, the inside fusion, while in the center appears a standard head with a nine-thread boss, twice the required number of threads for compliance with paragraph U-59 of the A.S.M.E. Unfired Pressure Vessel Code. An experimental die arrangement for welding bosses on saddled range boiler heads is exhibited in Fig. 21.

Some integral bosses have been cast more than 2 in. in height. Figure 22 illustrates some excessively high bosses for the minimal thread requirements. The lower bosses in this photograph are $^{3}/_{4}$-in. size integral bosses; the upper and the head bosses are 1 in. Figure 23 pictures the bottom boss in a flat, standard range boiler bottom. Figure 24 is another short-length shell with integral bosses; the back integral boss discloses the interior fusion of the boss.

A number of standard 30-gal. range boilers have been fabricated with integral bosses to demonstrate the practical value of the process.

After a group of components had been fabricated with integral bosses, they were assembled, welded, pickled, fluxed and galvanized. Figure 25 shows three galvanized, standard 30-gal. range boilers with integral bosses after the hydrostatic test.

Summary and Conclusions

Data and other evidence have been set forth to bring out the advantages of the integral boss in the thin-wall pressure vessel industry. These advantages may be summarized in general as follows:

1. The automatic welding process of depositing the integral boss eliminates the manual element of metallic arc welding.
2. Electrode wire is the only inventory item required to weld integral bosses from $^{3}/_{8}$- to $1^{1}/_{2}$-in. pipe-tap size.
3. Integral cast bosses are metallically sound and, therefore, are leakproof.
4. The sectional contour of the integral boss is especially advantageous for protective coatings; such as glass or enamelled linings, plastic linings and hot-dipped zinc coatings.
5. The integral boss cast on the external surface of the vessel wall provides good drainage openings that are not otherwise possible with flanged, peened or sleeve bosses.
6. Better stress conditions are provided by the integral boss and the notch effect of manual welds is eliminated.
7. The streamline appearance of the integral boss has greater sales appeal in the finished vessel.
8. Cost-wise, the integral boss is cheaper than the manually welded forged boss for openings in thin-wall pressure vessels in pipe-tap size of $^{1}/_{8}$ to $1^{1}/_{2}$ in.

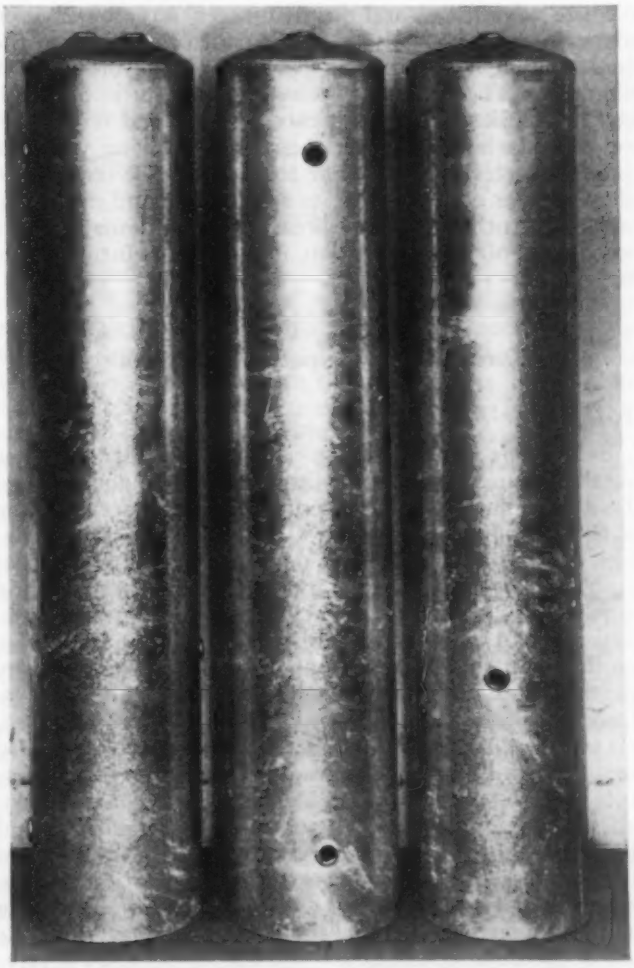


Fig. 25—Standard Galvanized 30-Gal. Range Boilers with Threaded Integral Bosses

Engineering Symposium of Future Control of Resistance Welding Machine*

By C. E. Smith†

THIS paper is in the form of a general description of the present and near future of resistance-welding controls. The present-day a.-c. single-phase control, synchronous and nonsynchronous, and their auxiliary equipment such as current compensators and voltage regulators, is given consideration along with the needs of present improvements of this type of control. Power factor correction, such as series capacitors on a single-phase a. c., its benefits and disadvantages are also commented upon. The stored energy type of control and machine, including the battery, the electrostatic capacitor type and magnetic stored energy type, with their definite advantages and disadvantages, have been given some thought, not only as to the control but also to the final welding result in the particular type of machine required. The frequency converter system is outlined, and its application to resistance welding and resistance-welding machines is given consideration along with the d.-c. converter type; similar to the dry disc rectifier 3-phase welder control, with its advantages and disadvantages over other types of present-day systems and the possibility of its application in the near future. See Fig. 1.

Direct Energy Types of Equipment

A.-C. Single-Phase Controls

Before this year of 1947, considerable confusion to the purchaser and user of resistance-welding machines and their controls was experienced as to the proper selection of the manufacturer's type of equipment or differentiation between one supplier s panel type against another supplier's type. It was not unusual to find that a certain aynchronous spot timer panel built by one control manufacturer had an entirely different type number than another control manufacturer's panel. It was felt by members of the Resistance Welding Manufacturers' Association that complete standardization was required, not only for designation of the types of controls but also because definitions of the various functionings of the controls would be of considerable help, and complete coordination between the control panel manufacturer and the resistance welding manufacturers would be required to bring about a settlement as to standardization and coordination of these controls. The possibilities of side mounted controls—that is, the controls mounted on the side of the welding machine—and the advisability of having such units were greatly reflected by the majority of the resistance welding manufacturers with the result that in March 1945 a joint committee of N.E.M.A. and R.W.M.A. was organized to discuss engineering standards for resistance-welding control.

A considerable amount of work was accomplished from the first meeting with an outline of the N.E.M.A. work in progress, the functions of the N.E.M.A. committee and various problems worked out as to the mounting, over-all dimensions, functions and uniform appearance and finishes of resistance welding controls. The over-all dimensions had to be given consideration, not only to synchronous timer equipment but for sequence timers and sequence weld timers as well. Various control combinations had to be given consideration so that the over-all dimensions should be as small as possible for each size of equipment. Products of the different manufacturers should have standard over-all dimensions. Over-all dimensions should be as important, if not more important, than any other item on the agenda, with consideration given to mounting hole spacings.

Various functions for which a welding control is designed to perform had to be defined clearly and numbers had to be given for ready reference with a uniform name. With the considerable progress that was made in the standardization of the welding controls during the year 1945, there remain only a few items on the agenda for further consideration.

The final work of the R.W.M.A.-N.E.M.A. Committee has brought about a complete line of side mounting controls which are a combination or of unit construction making it possible to mount the complete control on the side of the machine, thus allowing the machine to have the following good features:

1. The equipment comes completely wired making it unnecessary for the user of the equipment, during in-

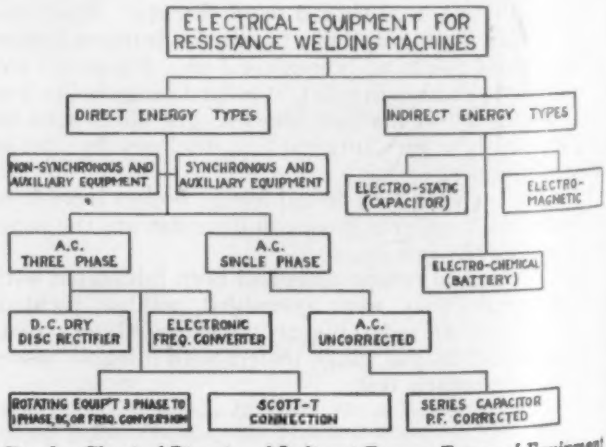


Fig. 1—Chart of Direct-and-Indirect Energy Types of Equipment

* Scheduled for Twenty-Eighth Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 19, 1947.

† Chief Electrical Engineer, The Taylor-Winfield Corp., Warren, Ohio.

stallation, to study and call in outside help for interconnections of the various units of the machine.

2. During installation of the machine there is only one piece of equipment to install, and the use of an integral combination unit eliminates the cost of mounting and places the controls in a more readily adjustable position.

3. The customer has only two power leads, two water leads and an air line to connect during original installation.

4. Upon movement of this welding machine to another location any time in the future, the disconnection of the air, water and power leads is very simple and reconnection can be had without referring to diagrams.

5. Simplification of wiring diagrams are a great aid to the customer and users of equipment as well as to the Resistance Welding Manufacturers Electrical Engineering Department, and Test Floors.

Identification of these various units is complete and is designated by N.E.M.A. type numbers with definitions of these particular types and their functions set down clearly and concisely with all resistance-welding control manufacturers following the standards as closely as possible.

A considerable amount of work was done on standardization of input terminals, wherein the various external connections such as foot switches, terminals, pressure switch terminals, etc., are designated and set up as N.E.M.A. standards.

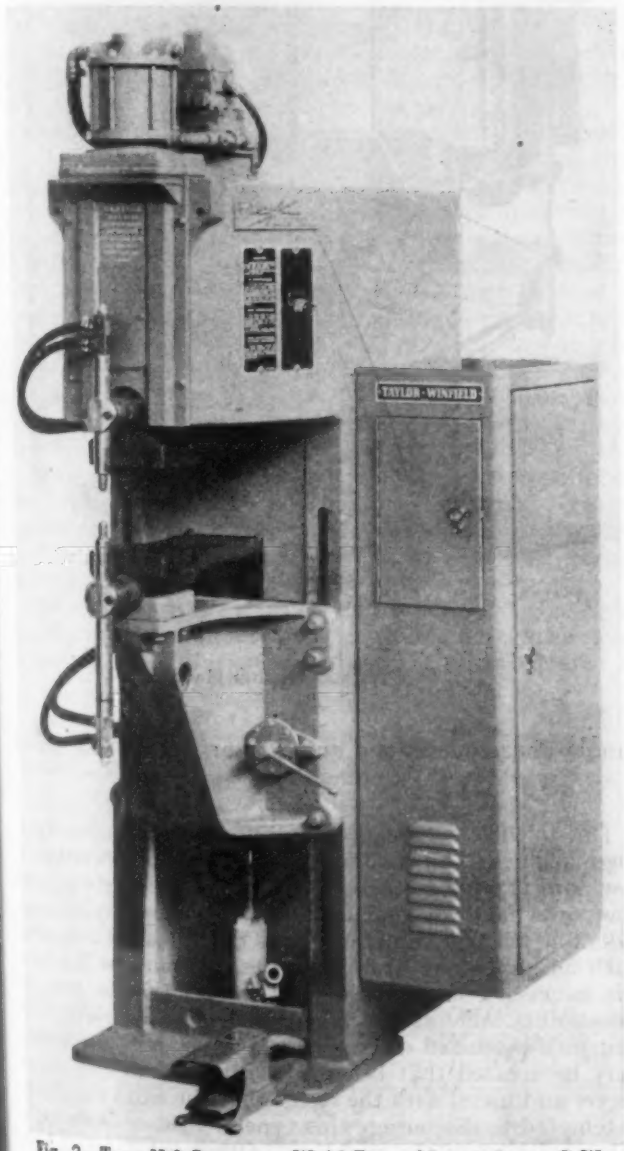


Fig. 2—Type N-2 Sequence Weld Timer Mounted on a R.W. M.A. Size 1 Machine

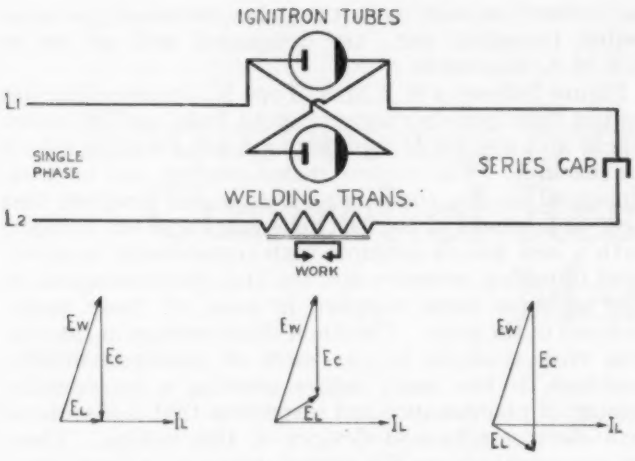
Figure 2 shows a N.E.M.A. Type N2, nonsynchronous control that furnishes squeeze, weld, hold, and off-times, repeat and nonrepeat functions mounted on the side of the machine. The control manufacturers can be complimented on the engineering design and progress that have been made in the last few years and for bringing forth a new line of controls with considerable improvement in timing accuracy and the high-grade components that are now being supplied in place of those manufactured in the past. The main disadvantage in the controls now available to the users of resistance-welding machines, is too many relays creating a considerable amount of maintenance and inspection that is associated with electromechanical devices of this nature. There are some controls on the market today that have eliminated all relays, with the exception of the head valve solenoid relay, but the tubes are numerous and the circuit is complicated. A considerable amount of effort should be put forth in the engineering divisions of the control manufacturers to produce nonsynchronous equipment with a reduction of tubes and relays.

In the very near future, resistance-welding machine users should expect to have available nonsynchronous control equipment with less complicated circuits, components, tubes and relays. Standardization of low-voltage initiating and safety circuits should be complete with 24 v. or below, so that personnel protection may be greatly increased. The addition of auxiliary units for 110 v., or low-voltage two-stage foot switch units should be eliminated with the control coming to the user, wherein, by adding a jumper or disconnecting a jumper, the unit can be single-stage or two-stage and 24 v. be accepted as standard initiating and safety circuit potential.

Synchronous Controls

The synchronous control which is the accepted precision timer has come a long way in the last ten years, and complete definition of its type and functioning has been set by the N.E.M.A.-R.W.M.S. committee. The synchronous timers now on the market should have considerably fewer components and tubes due to the constant effort of the design engineers to improve the circuit to a more understandable type of electrical equipment that can be maintained and analyzed by the type of personnel available at the present time. Any new designs of the synchronous panel including the spot and seam panel should give complete consideration to the facility of adding voltage compensators or current regulators. The unit should be so designed in mind that at any time by proper terminal connections, a voltage or current compensator could be added to the unit without completely redesigning the circuit or breaking into any leads for external connections between the two units. In conjunction with the synchronous timer panel and the ignitron contactor associated with this type of panel and with the nonsynchronous type of equipment, considerable work should go ahead on improvement of the ignitron igniters, and ignition characteristics to eliminate the necessary additional expense of loading resistors to produce consistent firing of the ignitrons with primary currents of 40 amp. or below.

There is a definite need for a small synchronous bench welding control to handle the precise current time in bench-welding applications. The present-day synchronous type of bench-welding control is entirely too expensive, and standardization should go forward on the



SERIES CAPACITOR CIRCUIT AND VECTOR VOLTAGE RELATIONS
IL = LINE CURRENT Ew = WELDER PRIMARY VOL.
EL = LINE VOLTAGE Ec = CAPACITOR VOLTAGE

Fig. 3

maximum time, as well as other decisions such as with or without heat control so that these units can increase their popularity by overcoming the high price of the unit, thus increasing the quality of weld required in bench-type work.

Voltage Compensator

The present-day voltage compensators on the market are entirely too complicated, not only in installation and setup during installation, but also because the type of personnel required to service and maintain this equipment cannot be expected to be found in the field. Present-day circuits are limited in their speed of operation and compensation. They will compensate at 3 cycles for sudden drop in voltage, and very seldom are they found to operate with all of the electronic welding controls manufactured by the supplier of the voltage compensator.

Current Regulator

The present-day current regulator now in the market is another complicated circuit with a multitude of tubes requiring a design engineer or an experienced electronic engineer to service and maintain. The set-up time during initial installation of this unit is high, and the speed of correction for any instantaneous variation in current limits its application, particularly on seam welders. For best operation and full compensation, the weld current off-time should not be less than 4 cycles, and the on-time not less than 6 cycles. The application is then generally used with a spot-welding machine for correction of voltages required due to impedance change caused by the material feeding into the throat of the machine, or on similar cases with seam welders where welding current is flowing continuously.

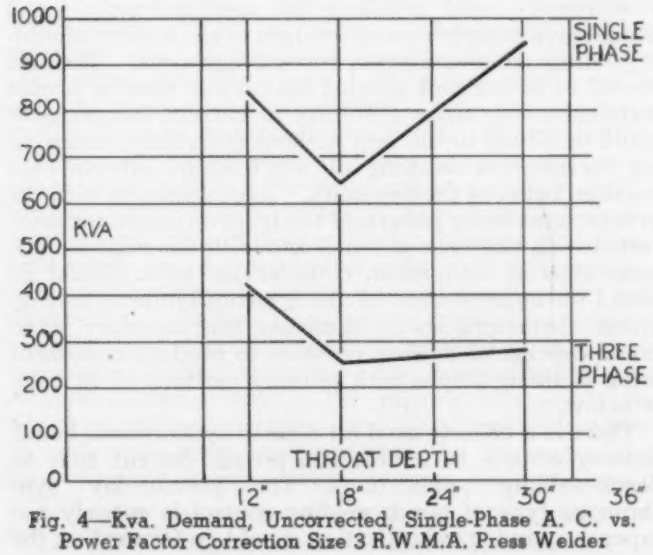


Fig. 4—Kva. Demand, Uncorrected, Single-Phase A. C. vs. Power Factor Correction Size 3 R.W.M.A. Press Welder

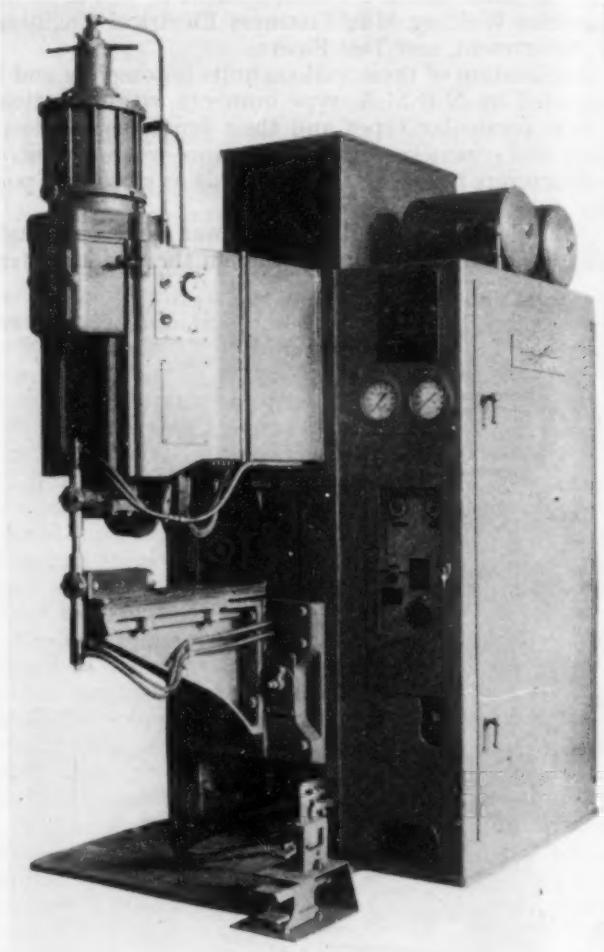


Fig. 5—Dry Disc Rectifier Machine

Single-Phase Machines and Power Factor Corrected Machines

Due to the secondary configuration of resistance-welding machines, the machine is essentially a low-impedance, low-power factor device. The kva. is generally high and the power factor is generally low, and thus there is considerable reactive component loss that must be reckoned with as far as the ability of the machine to produce the necessary heat to make a weld. In the case of heavy-duty welding machines, with high instantaneous demands produced on the supply lines, a cyclic flicker may be created that becomes a nuisance to the power server and users, with the result that the utility engineer is tempted to discourage this type of load or force some other solution of the problem. Other solutions of this problem created by the decision of the utility engineer,

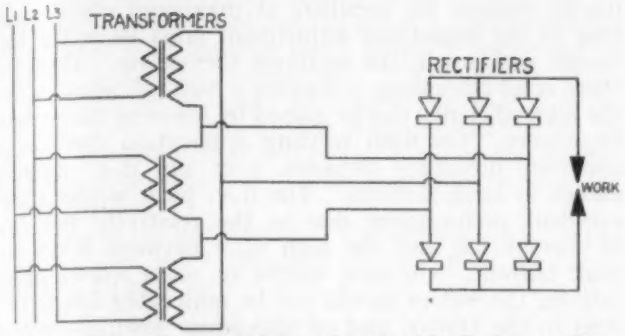


Fig. 6—Three-Phase Full Wave Circuit of D.-C. Current Dry Disc Rectifier

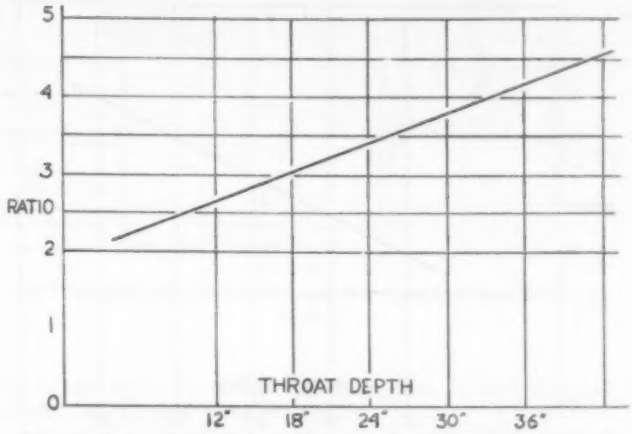


Fig. 8—Ratio of Single-Phase Kva. to Three-Phase Kva. (Dry Disc Rectifier) on Size 3 R.W.M.A. Press Welder

in some instances, have been wrong when some other solution was less economical. The utilities expect a fair return in all cases for their service of any type of load, but the economy of the welding processes are such that they can fully support the cost of service or any demand revenue that can be taxed to the users of the equipment. However, it is not a simple problem to subject to the customer, who expects fairness and freedom from tariffs, the elimination of the possibility of continued use of this type of load.

When the economics of the final solution of installation of a welding machine in regard to the utility problem dictate the correction of the welding machine itself, there are various ways of attempting to improve the kva. demand of that particular welding machine.

Series-capacitor power factor correction applications have been numerous and have been very successful and with the present engineering information that is available for calculations of the necessary capacitors to correct a given welding job, it makes it a rather simple problem. Besides being more expensive as a correction device, the series capacitors have definite disadvantages in that a certain turns ratio of the transformer must be selected and adhered to, making it more or less applicable to one job, unless the welding manufacturer is informed of the line of work which this machine is expected to do. In some instances, machines have been corrected with series capacitors to correct the kva. and power factor during the welding of aluminum, and by means of selector switches inserted to change turns ratios of the transformer making it possible to weld mild steel and, in some instances, stainless steel (see Fig. 3 which shows an elementary circuit and voltage vectors of series capacitors).

One of the arguments against series capacitors has been that the machine must remain at approximately the same secondary configuration, and that if the throat area is changed, it is necessary that an expert be had to revise the tuning or determine the correction of the circuit to bring it back to approximate unity power factor. However, if the welding machine is so designed with a maximum of throat configuration necessary for the job, and consideration given to the application of the job, that the customer expects to weld in the future, the series-capacitor equipment becomes in some instances less expensive with a large throat machine than a small throat machine. Therefore, if the demand has been corrected, and the power company can service such a demand, there is no reason why the secondary configuration should be changed.

Another factor that increases the cost of series-capacitor power factor correction equipment installation is the cost of the control panel. This panel must be of the 2300-v. variety, or out of the class of the standard 600-v. a.-c. controls. Another alternative is to make use of an auto transformer and reduce the input line voltage to a low value wherein the capacitor voltage plus the line voltage does not arise to over 600 v., so that the ignitron contactor or nonsynchronous type of equipment can be used along with the standard 440-v. welding transformer primary. Figure 4 is a graph showing the kva. and kw. demands of a corrected and an uncorrected machine.

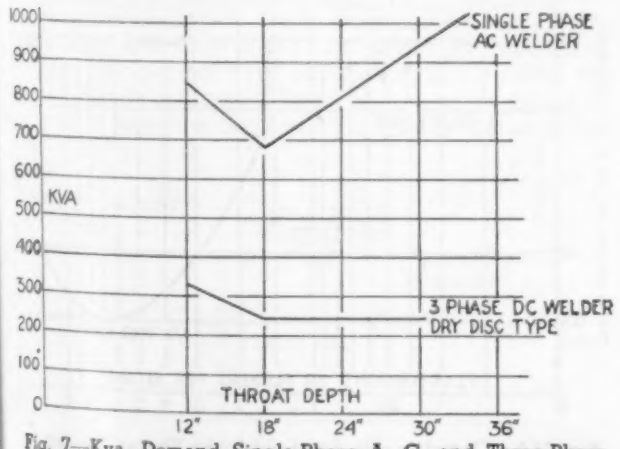


Fig. 7—Kva. Demand Single-Phase A. C. and Three-Phase D. C. vs. Throat Depth Size 3 R.W.M.A. Press Welder

The Dry Disc Rectifier

A 3-phase dry disc rectifier machine that is capable of delivering d.-c. current into the secondary of the welding machine making it possible to produce a 3-phase lower kva. demand than the conventional single-phase welder, is one answer to means of handling the problems of lowering the high instantaneous demands found in the single-phase a.-c. welding machine. This type of welder

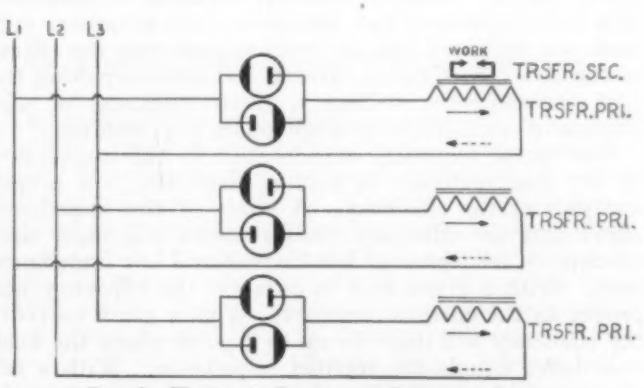


Fig. 9—Electronic Frequency Converter System

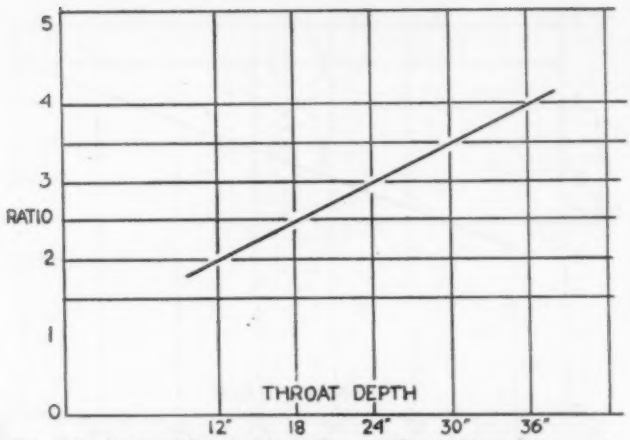


Fig. 10—Ratio of Single-Phase Kva. to Three-Phase Kva. (Frequency Conversion) on Size 3 R.W.M.A. Press Welder

can be a seam, spot or pulsation welder and may be applicable to flash welders. The rectifier stacks have an exceptional long life and are small in size as compared to other types of electrical components, and are of rugged construction. See Fig. 5 for a photo of a dry disc rectifier machine. They are very suitable to a welder load, being capable of standing heavy current overloads, with power consumption at no load practically nill. For the most economical transformer design and most satisfactory rectified wave form for the particular d.-c. output voltage and current required in a resistance-welding machine of this type the rectifier circuit should be three phase full wave (see Fig. 6). The dry disc rectifier type of a machine uses no welding transformer and with the 3-phase full-wave circuit, in comparison with the 3-phase half-wave circuit, it is much more efficient and economical. The kva. demand, to make a given weld in comparison to a.-c. or any frequency conversion system, will be less, and since we are welding with d.-c. current, the effect of the secondary configuration is less noticeable as to electrical losses. Figures 7 and 8 show a comparison of the ratio of the 3-phase kva. demands on a dry disc rectifier machine in comparison to a single-phase a.-c. machine.

Due to the values of the resistance and inductance found in a welding machine the rate and rise of current in a dry disc rectifier machine is slow, making it very desirable for projection and push welding. The current rise is faster than any calculated values from R and L, due to the fact that the load sees a changing voltage. At the start of the current rise, the applied voltage makes the current start in a manner that makes the apparent maximum current about twice the actual maximum. Approximately 8 millisec. after start of current, the voltage drops to a low constant value because of the overshooting tendency of the current rise pattern. This rate of rise of current to maximum may be detrimental in some types of aluminum welding, but again in consideration to the values of kva. demands, more secondary current can be forced into the weld to overcome the effects of the slow rate of rise in current, and thus keep down the kva. demand when welding a given thickness of aluminum in comparison to single-phase a.-c. welding.

One factor requiring consideration in the application of dry disc rectifiers in welding machines is a proper analyses of the efficiency. A study of the impedance curve and the efficiency measurements will show that efficiencies are lowest at low current and low impedance load. With a given load impedance, the efficiency improves as the current increases. With a given current, the efficiency will improve up to a point where the load impedance equals the rectifier impedance. With a resistance welder application there is no object in attempting to operate the rectifiers at maximum efficiency as long as the impedance adjustment must be in the load circuit and not in the rectifiers themselves. However, there is no advantage in having a high efficiency, unless the high efficiency can be gained by lowering the rectifier impedance. On flash welding application there is no apparent difference between a.-c. and d.-c. welding, except in large sections. The d.-c. push welder shows excellent performance due to the relatively low rate of current rise and the high ratio between RMS and peak current. On spot welder or seam welder applications, the welder should not be noticeably affected by steel in the throat, and on aluminum welding cleaning should be less critical than either Hi-Wave or a.-c. welding. Double pressure timing should not be as critical as on normal a.-c. spot welding.

Frequency Converter System

The use of frequency converter systems to reduce the frequency of the secondary current to a low value, thus reducing the inductive reactance of the secondary loop circuit, has considerable merit as to the reduction of the kva. demand. One leading resistance-welding manufacturer must be complimented on the improvements made

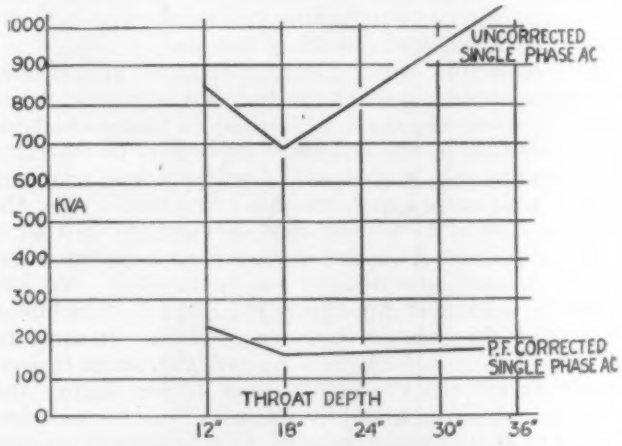


Fig. 11—Kva. Demand, Single-Phase A. C. and Three-Phase A. C. (Frequency Conversion) vs. Throat Depth Size 3 R.W.-M.A. Press Welder

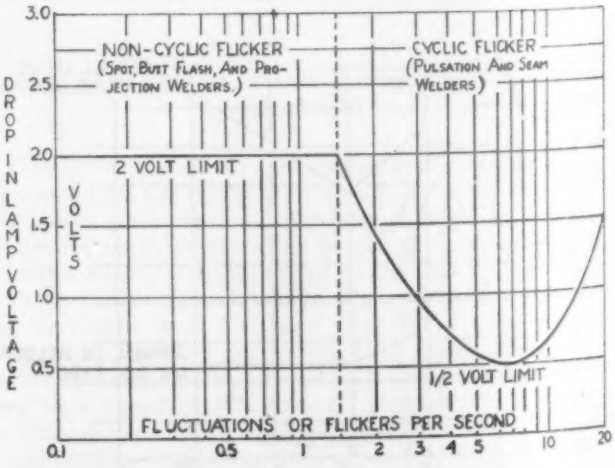


Fig. 11A—Objectionable Limits of Light Flicker Caused by Welder Loads

in the costs of this type of converter by eliminating the rectifier transformer and making use of a 3-phase welding transformer with ignitron tubes properly connected for 3-phase, half-wave rectification. The welding transformer must be designed to handle the very low frequencies (5 to 10 cycles), but with elimination of the rectifier transformer, it brings the price of this control somewhat competitive with other converter types or correction systems.

To sum up the low-frequency converter system, certain electronic frequency changing circuits draw an almost balanced 3-phase power from the line and have a low-frequency, single-phase output. Because power factors increase when the load is operated at a low frequency a double advantage can be had from such an electronic circuit. Commutation faults, however, introduce drawbacks to use of a low-frequency system, and during one or more cycles (on supply frequency basis) the entire load is single phase, resulting in a momentarily increased voltage drop of two lines. Even though this momentary drop will have a very small value when read on an RMS meter, it may cause objectionable light flicker. The only drop that must be considered in analyzing the possibility of light flicker is the drop on the loaded phase line. Figure 9 shows a view of a frequency converter system and welding circuit, and Figs. 10 and 11 show the comparison of the 3-phase kva. demand to single-phase kva. demand.

One of the improvements that can be made to the converter system is the zero current gaps during the transfer, or change in polarity of the secondary current. With the introduction of zero current gaps during current flow, the impulses per second or flickers per second fall in a range of approximately 9 per second, or within the $^1/_2$-v. limit, commonly termed the cyclic-flicker range similar to pulsation or seam welding on and off timing periods (see Fig. 11A). The possibilities of changing the frequency on these controls, since they are variable, may be detrimental rather than advantageous, and since the frequency is variable and is fairly high up on either side of the cyclic flicker V-curve, it is quite likely that at some time during the life of the installation the frequency will be changed, and the welds made at the detrimental frequency of 7 or 8 pulses per second.

The frequency converter system is somewhat likened to the dry disc rectifier in that since it is a high power factor device, it is resistance-conscious and generally no current compensation is required or any correction necessary for the introduction of magnetic material in the throat of the welding machine.

Rotating Equipment

To offset an inadequate power supply, motor-generator sets have been used; but due to their original cost, maintenance cost and their short time transient regulation, they have not proved very satisfactory. To offset the first two disadvantages, a large M. G. set is generally employed to handle a bank of welders, but the transient

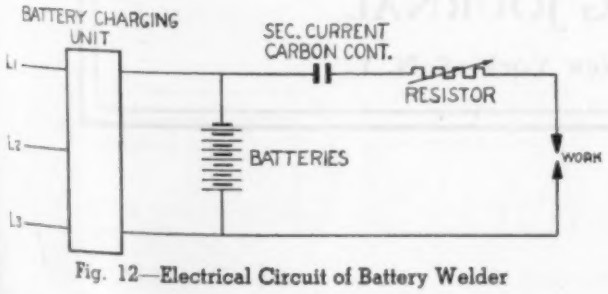


Fig. 12—Electrical Circuit of Battery Welder

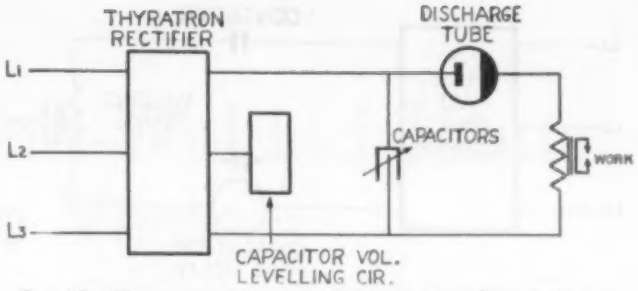


Fig. 13—Elementary Diagram of Electrostatic Stored Energy System

reactance with simultaneous operation of the machines makes this system undesirable.

A motor-generator set, with 3 phase input and single phase output of commercial frequency or low frequency, may have satisfactory application to a single machine, that is, one M.G. set per welder. The problem of interrupting the heavy sec. currents may rule out this type of application.

Indirect Energy Types of Equipment

Battery-Operated Machine

The battery-operated welding machine is another stored energy device, wherein the energy is stored in the battery. It can be considered as being in the same category as the Hi-Wave, which stores the energy in electrostatic capacitors, and the Sciaky stored energy system which stores the energy in the magnetic field and iron of the transformer. The writer believes that the battery-operated machine has a place in the resistance-welding field, particularly where the customer is on the end of a line or in a rural district wherein the slightest kva. demand will produce objectionable light flicker in the community. We have some instances and indications where the power company would object to a 15- or 20-kva. demand. In this instance, a 3-phase converter or other power factor corrected machines would not be able to meet these low kva. restrictions. This battery system is the same as all stored energy systems, wherein to meet a rate of production you must store the energy fast enough to meet the required rate. The higher the production, the higher the energy taken from the line for meeting these requirements. If it takes so many ampere seconds to make a weld, and it is necessary to maintain stable energy to the battery, the same ampere seconds must be put back into the battery during the no-weld period. The writer has no cost of these battery-operated machines to give a comparison against the single-phase series-capacitor power factor equipment and frequency system. Figure 12 is an elementary electric circuit of a battery welder.

Electrostatic Stored Energy Welding Machines

This system is a means of storing electrical energy into a bank of capacitors and discharging this energy into the welding transformer through the secondary and into the weld material to make a weld. Figure 13 is an elementary circuit of the capacitor stored energy system. The capacitor for storing the energy is generally charged with a 3-phase, full-wave rectifier, with the impedance of the total rectifier system so adjusted by high-impedance rectifier transformers to limit the kva. demand to approximately 35 to 50. With its ability to make very consistent high-quality welds, due to its stable energy feature, the stored

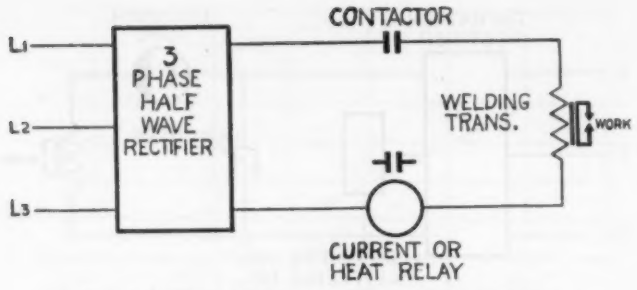


Fig. 14—Electro Magnetic Stored Energy System

energy machine is still a machine to recommend for the welding of aluminum to meet Army and Navy specifications. A considerable amount of engineering time and effort has been spent to reduce the cost of 3-phase, stored energy systems with the possibility of a single-phase unit that will meet approximately the same spots per minute that the 3-phase units did in the past. Constant effort has been made to eliminate all working relays by interposing completely electronic tube circuits.

The electrostatic and magnetic types of stored energy machines have their limitations in that they are not suitable for welding wherein a slower rate of rise and longer time of current flow are desired. However, the electrostatic stored energy and the electromagnetic stored energy machines are very flexible as to current wave shapes and various values of capacitance, voltage and turns ratio will produce the most desirable type of current wave shape. One disadvantage of the stored energy systems in the electromagnetic or electrostatic type is that the economics go out of reason when trying to secure higher energy levels above 15,000 joules. Not only does the capacitor cost rise, but the transformer must have sufficient iron to prevent saturation at these large amounts of energy. The system becomes somewhat slow in charging time of the capacitors if the kva. demand must be kept within a nominal figure.

Magnetic Stored Energy Systems

Figure 14 is an elementary circuit of the electromagnetic stored energy system. This process is based on the ability of a changing current to induce a voltage. Although the welder operates from a a.c. supply line, it is a d.c. process employing d.c. current from a 3-phase half-wave ignitron rectifier. The welding transformer secondary, through its property of mutual inductance, supplies the heavy short time welding current when the d.c. current in the primary of the transformer is suddenly interrupted. As long as the contactor remains closed, energy remains stored in the transformer. When the contactor opens, the rate of current flow disminishes as fast as is allowed by the transformation of magnetic energy into heat.

Summary

In summing up the above, it appears that (1) the a.-c. single-phase machine is still the machine for general-purpose welding and average installation; (2) various improvements should be made on the electronic control panels to eliminate the heavy usage of relays and lower the tube complement; (3) the voltage compensators and current regulators are entirely too complicated in design, and will not fit the full range of application; (4) d.-c. current welders, like the dry disk rectifier schemes and the frequency converters, are exceptionally good devices for lowering of the kva. demand and placing the demand on the 3-phases. The rate of rise of current and the resistance-conscious characteristics of these machines may be detrimental on certain types of material in comparison with a.-c. welders, but when consideration is given to the lowering of the primary kva. demand and that they are 3-phase devices, it appears that in the immediate future considerable amount of the 3-phase devices, such as mentioned, will gain considerable popularity in the heavy-duty machine applications.

DISCUSSION—ANNUAL MEETING PAPERS

Written discussion of any or all of the Annual Meeting papers given in this and subsequent issues is invited. This discussion should bring out supplementary information, or restatements of the problems and solutions to add to their clarity. Discussions, together with illustrations should be sent to:

W. Spraragen, *Editor*

THE WELDING JOURNAL

33 West 39th Street, New York 18, N. Y.

Development of Butt-Welded Joints in Pressure Vessels*

By Edwin J. Brown†

THE use of the butt-welded joint in pressure vessels is one of the best examples of the complete displacement of the riveted joint by the all-welded joint. These welded joints uniting longitudinal and girth seams of cylindrical vessels (Fig. 1) for Power Boilers, U-68 Unfired Pressure Vessels and certain A.P.I.-A.S.-M.E. Vessels, are subject to critical inspection not ordinarily encountered in any other kind or type of joint. Yet, despite the cost and difficulties encountered in this inspection, the welded joint has proved less expensive, safer, and has given industry the tremendous advantage of higher operating pressures and temperatures. In the case of power boilers it has eliminated to a great extent the condition of stress and opportunity of concentration necessary to intergranular corrosion. The development of methods for making, economically, butt-welded joints has made this possible and is therefore of first importance in building all-welded pressure vessels. Manufacturers have concentrated their efforts on procedures, techniques, processes and machines to make the required high-quality all-welded joints at the least possible cost.

The original or basic design of quality butt joints is as shown in Fig. 2. This is the familiar U-groove made in preparation for the manually fabricated joint. This was made in a series of operations:

1. Shearing plate edges to remove excess metal.
2. Planing of plate edges to form U-contour.
3. Assembling parts to form groove.
4. Welding, multiple pass in U-section.
5. Chipping of back side to remove unfused metal.
6. Welding of chipped groove on back side.
7. Grinding of weld to proper finish.

Each was time-consuming and difficulties existed in several of the operations making it desirable to revise the joint design. The redesign was based on a study of each of these operations and a more expedient method or means of fabrication was chosen.

Operations 1 and 2—Shearing and Planing of Plate Edges to Form U-Contour

The immediate thought was to replace shearing and planing with flame cutting, a faster, more economical way of plate edge preparation. This method, however, was not practical in forming the U-grooved edge on a production basis. It was then decided, if possible, to design a groove with straight and bevel cuts only to utilize flame cutting.

Operation 3—Assembling Parts to Form Groove

In assembly, the $^1/_8$-in. wide lips at bottom of U-groove were troublesome because of difficulty in getting good alignment. These surfaces in actual fit-up often overlapped half their thickness. As a result, the first welding bead in bottom of groove was made with a $^3/_{16}$-in. or smaller electrode to avoid burning through. It was advantageous to increase width of abutting edges and eliminate the use of the smaller electrode.

Operation 4—Welding, Multiple Pass in U-Section

As the joints were manually welded this step could not be improved upon. The submerged melt process was considered and it was decided that at some future time this method would be used and, in the redesigned joint this was to be considered. However, for the present, we were to continue manual welding.

Operation 5—Chipping of Back Side to Remove Unfused Metal

This had been a constant source of trouble because of lack of skilled men and unwillingness of workmen to learn this laborious trade. The flame gouging torch was chosen to replace the chipping hammer. Because of the hot conditions which existed in the gouging operation it was impossible to use this method of removing excess metal within the confines of a pressure vessel. The solution was to design the joint so unfused metal could be removed from the outside.

Operation 6—Welding of Chipped Groove on Back Side

As joints in pressure vessels for this service are of the double butt type it is necessary to weld from both sides of joint. The welding on back or inside should, because of operator exposure to heat and smoke, be kept to a minimum. The limit was placed at two passes with $^1/_4$ in. as max mum diameter of electrode. The remainder of the thickness was to be welded from the outside.

* Scheduled for Twenty-eighth Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 19, 1947.

† Union Iron Works, Erie, Pa.

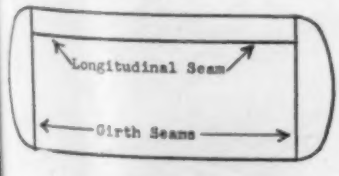


Fig. 1—Cylindrical Vessel

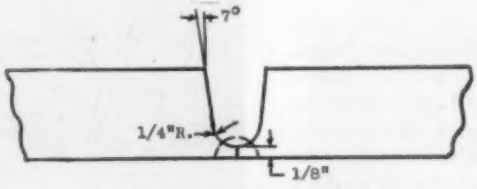


Fig. 2—Original Joint Design

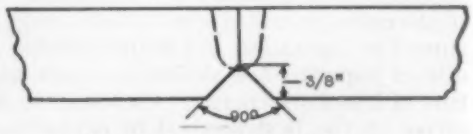


Fig. 3—Revised Joint Design

Fig. 4—Normal Weld, Top. Deep Penetration Weld, Bottom

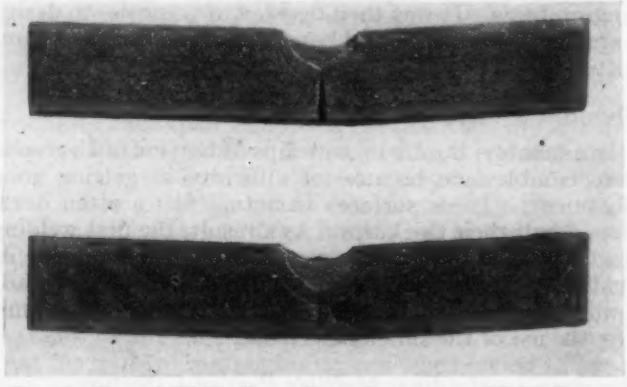


Fig. 5—Normal Weld, Top. Deep Penetration Weld, Bottom

Operation 7—Grinding of Weld to Proper Finish

Grinding was done with portable air machines using 1- x 6-in. abrasive wheels both inside and outside of joint. Outside grinding time could be reduced by application of a large foundry-type grinding machine. This heavy grinder would have a flexible mounting to allow the grinding machine to be located at girth and longitudinal seams. This operation would not be affected by joint design but as we were considering improvements in operations, as well as redesign, this operation was considered.

The summation of the results of this study gave us a joint with straight and beveled edges, the straight or abutting edges to be of considerable width and so located with reference to vessel that unfused metal could be removed from the outside, and that no more than two passes would be required inside, also that submerged melt processes could be applied without change in joint. These joint characteristics were found in the design shown in Fig. 3, and the series of operations to complete joint would be:

A. Flame cutting edges to contour.
B. Assembling parts to form joint.
C. Welding back side of joint.
D. Flame gouging unfused metal from outside.
E. Welding, multiple passes in flame-gouged groove.
F. Grinding of weld to desired finish.

This design looked feasible, and it was decided to attempt application preliminary to production. Each operation, if successful, would give us an advantage of less time consumed per operation and would simplify all operations to a level requiring less skillful oprators, and with expenditure of less work energy. Each operation was studied to arrive at the best method of performing the described work.

Operation A—Flame Cutting Edges to Contour

A heavy machine of tractor type as generally used in flame cutting was purchased and on this was mounted a floating adjustable nozzle block. The purpose being to allow the nozzle block to ride on work and maintain a fixed distance between cutting nozzles and work, and to facilitate adjustment to make the various combinations of bevel and straight cuts required. The performance of this equipment exceeded our expectations and eliminated both shearing and planing operations. Time of operation was less than that of the previous single operation of planing.

Operation B—Assembling of Parts to Form Joint

This operation was simplified since the wide abutting edges were easily matched and did not slip out of alignment during assembly. Large electrodes could be used without danger of burning through.

Operation C—Welding Back Side of Joint

In the V-groove two beads were to be deposited with $^1/_4$-in. electrode, but on examination of cross section of weld after depositing first bead, we found as Figs. 4 and 5 top illustrate, a lack of penetration into the bottom of the groove. It was then decided to use the deep penetration technique of welding on the back side to secure greater depth of weld. This technique involves the use of

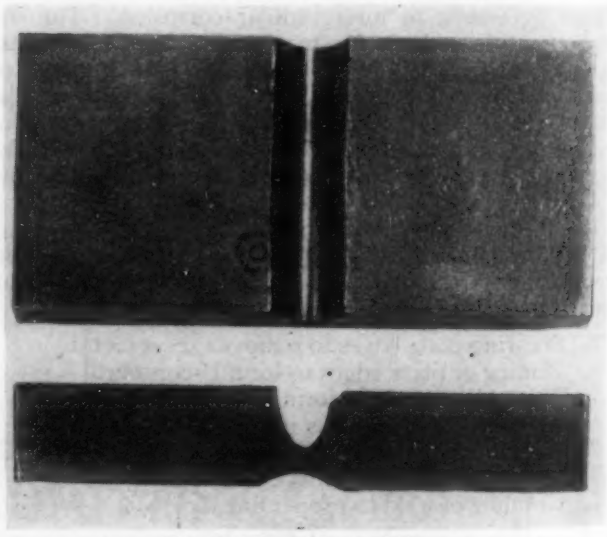


Fig. 6—Flame-Gouged Groove

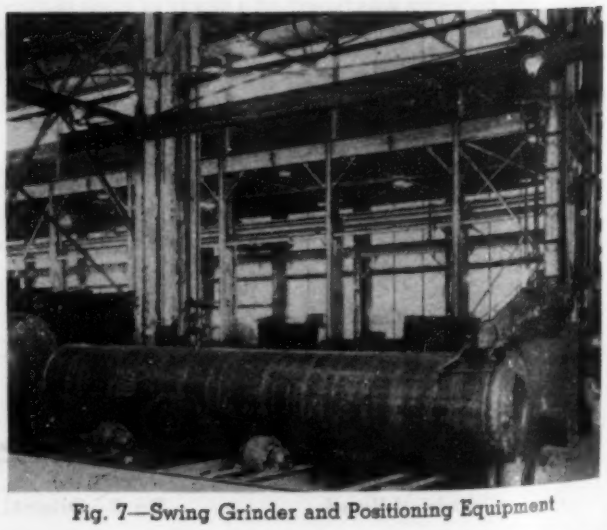


Fig. 7—Swing Grinder and Positioning Equipment

SPECIFICATIONS, PROCEDURES & TECHNIQUE
METAL ARC WELDING PROCESS

Procedure Specifications For Metal Arc Welding
Power Boilers and Unfired Pressure Vessels

Specification No.4
February 5, 1945

PROCESS

The welding shall be done by the metal arc process.

BASE METAL

The base metal shall conform to the specifications for SA-70 or SA-212 carbon and carbon silicon steel plates as designated by the A.S.M.E. Code "Specifications for Materials".

FILLER METAL

The filler metal shall conform to Classification Number E6030 or E7030 of the A.S.M.E. Code "Specifications for Materials".

POSITION

The welding shall be done in the flat position.

PREPARATION OF BASE MATERIAL

The edges or surfaces of the parts to be joined by welding shall be prepared by gas cutting as shown on the attached sketches and shall be cleared of oil oil or grease and excessive amounts of scale or rust, except that a thin coat of linseed oil, if present, need not be removed.

NATURE OF ELECTRIC CURRENT

The current used shall be Alternating, 60 cycle.

WELDING TECHNIQUE

The welding technique, electrode size, and mean voltages and currents for each electrode shall be substantially as shown on the attached sketch. The first pass is to be made on the underside of the plate (position flat) with the electrode held in a vertical position, sloping approximately 60° in the direction of welding. A short arc shall be held by dragging the electrode coating on the base material.

CLEANING AND GRINDING

All slag or flux remaining, or any bead of welding shall be removed before laying down the next successive bead. The finished welds shall be ground flush with the base material.

DEFECTS

Any cracks or blow holes that appear on the surface of any bead of welding shall be removed by gas gouging before depositing the next successive bead.

TREATMENT OF TOP SIDE OF WELDING GROOVE

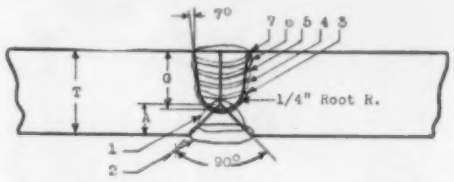
The top side of the welding groove shall be formed by gas gouging to a depth necessary to disclose sound or homogeneous metal. The groove shall be thoroughly cleaned, all oxide removed, before welding.

RADIOGRAPHIC EXAMINATION AND HEAT TREATMENT

All vessels welded may be radiographed and/or stress relieved as required by the provisions of the A.S.M.E. POWER BOILER OR UNFIRED PRESSURE VESSEL CODES.

WELDING PROCEDURE

Thickness Over 3/8"



T	3/8 "	1/2 "	5/8" to 1-3/8"	BEAD	ALL THICKNESSES-(T)*			
G	3/16"	1/4 "	T-A=G	1	1/4" Rod	365 Amps	42V	
A	1/4 "	5/16"	3/8" Constant	2	1/4" Rod	365 Amps	42V	

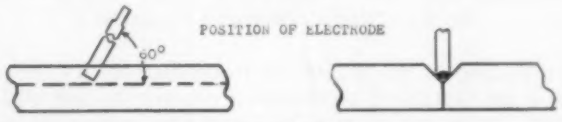
*Thicknesses 3/8" & 1/2" Bead 1 only req'd., backside

BEADS IN GOUGED GROOVE OF DEPTH "G"

Each Bead 1/4" Rod 320 Amps 38V

"T"-THICKNESS	"G"-GOUGED DEPTH	BEADS REQ'D.
3/8"	3/16"	1
1/2"	1/4"	2
5/8"	5/16"	2
3/4"	7/16"	3
1 "	11/16"	5
1-1/4"	15/16"	8
1-3/8"	1- 1/16"	9

POSITION OF ELECTRODE



Record of: Process Qualification
Manufacturer: Union Iron Works, Erie, Pa.
Welding Operator: Howard Himes, Designating No. 13
Signature Howard Himes

Material: Kind - Plate Specification SA-70 T.S.55000
Thickness: 1 inch Welding Position - Flat
Welding done in accordance with Mfg. Specification No. 4, Date Feb. 5, 1945

Reduced Section Tensile Test

Spec. No.	Width	Thickness	Area	Ultimate	Unit Stress
P-1	1.503	.826	1.24	33,000	61,500
P-2	1.506	.835	1.25	38,700	61,600

Both specimens failed in plate.

Free Bend Test

Spec. No.	Gauge Before	Gauge After	Difference	Percent
P-3	.656	.921	.265	40.3
P-4	.609	.890	.281	45.2

No sign of cracking or tearing.

Side Bend Test

Spec. No.	P-5	No sign of cracking or tearing
Spec. No.	P-6	" " " " " "
Spec. No.	P-7	" " " " " "
Spec. No.	P-8	" " " " " "

The undersigned manufacturer certifies that the statements made in this report are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of the A.S.M.E. Code "Welding Specifications".

Fig. 8—Procedure Specification and Qualification

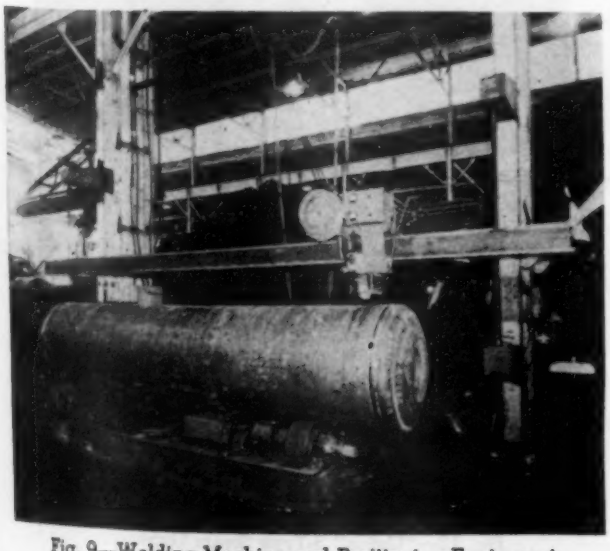


Fig. 9—Welding Machine and Positioning Equipment

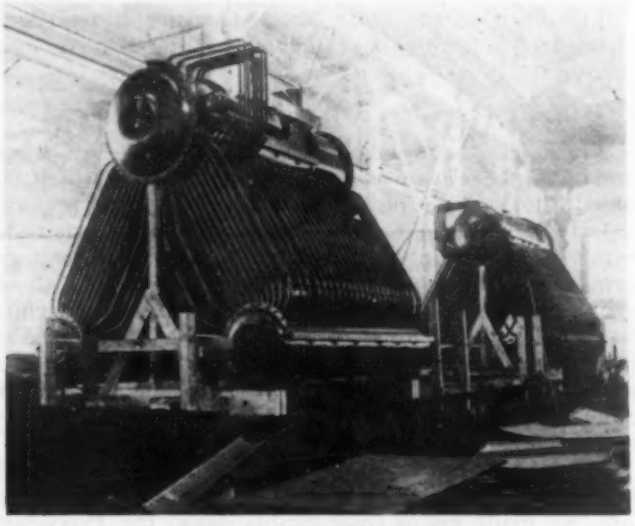


Fig. 10—Yarrow Type Boiler

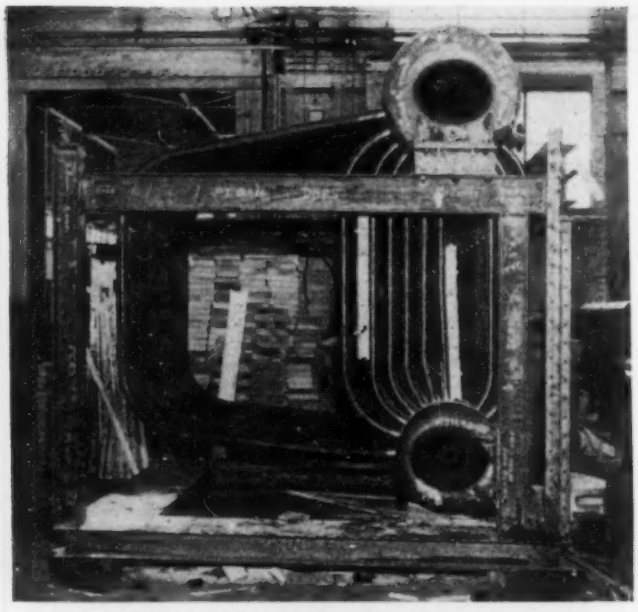


Fig. 11—"Union" Dowtherm Generator

high amperages, the maximum recommended by the electrode manufacturers, to obtain a digging action and secure the deep penetration necessary to weld root of V. After experimental work the V-groove was satisfactorily welded and cross-section of this weld was shown in Figs. 4 and 5, bottom.

Operation D—Flame Gouging Unfused Metal from the Outside

A considerable amount of metal was to be removed with this type of groove and a large volume could be removed by this process in a very short time. First attempts proved a torch with 180° Monel head was most applicable and largest standard gouging tips were used. As it was impossible to remove all metal on one pass of torch, multiple passes were tried but we found in heavier sections the groove was not wide enough to permit easy welding. A gouging nozzle was then secured one size larger than the manufacturer's standard and in three passes of the torch we could remove all unfused metal in thicknesses to approximately $1^1/_4$ in. This is a very rapid method of metal removal and the gouging torch became a versatile tool. A typical gouged groove is shown in Fig. 6.

Operation E—Welding, Multiple Passes in Flame-Gouged Groove

This remains the same, weld structure and physical characteristics were not affected by the flame-gouged groove.

Operation F—Grinding of Weld to Desired Finish

A grinder was purchased carrying a 12- x 2-in. wheel and mounted on an overhanging framework which enabled the vertical placement of grinding over pressure vessel. The vessel, for girth seam operations, was to be rotated under grinder and, for longitudinal operations, grinder was to be moved over vessel. Figure 7 shows grinder setup. We have decided to add another machine to enable grinding to take place on two girth seams simultaneously. The second grinder is to be a heavier machine carrying a 18- x 2-in. wheel which will give us more rapid metal removal and yet retain the flexibility necessary.

This revised joint required processes and methods with which our welding organization was not familiar, therefore, we made up in considerable detail the Procedure Specification as required by the provisions of the A.S.M.E. Code. On examination of the Specification shown in Fig. 8, you will notice details include explicit instructions on position of electrode which is of first importance in the deep penetration welding technique. Also as part of the Procedure Specification, the Procedure Qualification is shown. This covers qualification of these welds on A.S.M.E. Material Specification SA-70 steel. Note that both tensile strength and ductility are excellent. As this indicates welds made in actual production were entirely satisfactory and considerable reduction in fabricating time was made.

Upon purchase of a submerged melt welding machine we immediately set it up for welding outside of joint. The groove as shown in Fig. 7 of Procedure Specification is used to thicknesses of $^{23}/_{32}$ in. The base metal on outside of joint is not gouged out and in welding with the machine, penetration is secured through abutting edges to manual backing weld inside. As joint outside is made almost entirely of base material, weld metal accumulates on outside of joint and would present a problem except that the swing grinder removes this excess in comparatively short time. In thicknesses over $^{23}/_{32}$ in. we adopted the usual double bevel and land edge preparation with equal success. Here the flame-cut edge again proved its economy in making both the bevels and land in a single operation. The welding machine is mounted on a carriage which travels on a traversing beam supported on either end by a manually turned screw. This gives vertical adjustment. The vessel is placed on a rotating device and is rotated for girth seams, welding head moves on the traversing beams for longitudinal seams (see Fig. 9). This simple arrangement limited our initial difficulties in utilizing the submerged melt process, i.e., we did not encounter those common to installations including large intricate work positioning equipment. These positioners have been built by many manufacturers to facilitate and enable application of machine welding to both inside and outside of joint, but in all cases will allow only inside welding of longitudinal joint and girth seams to, but not including final seam, which is ordinarily the welding of closing or second head. Furthermore, they are restricted to minimum diameters of approximately 48 in.

On installation of welding machine the question of qualification of process arose. As the A.S.M.E. Codes do

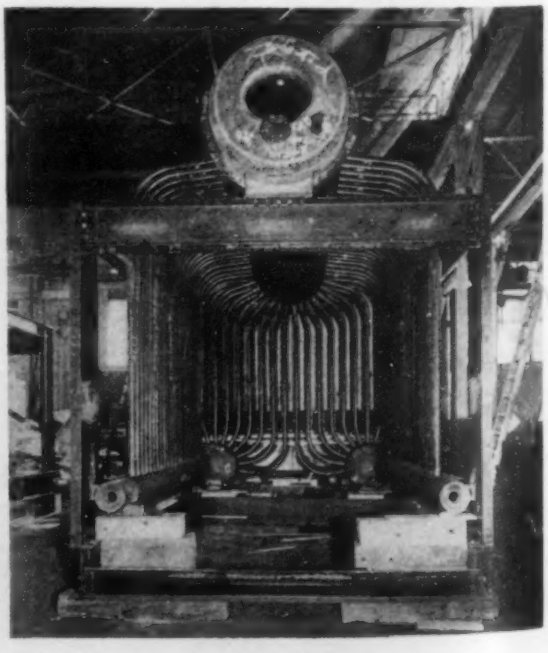


Fig. 12—"Union" S-Type Steam Generator

not refer directly to the submerged melt process, we wrote to the Boiler Code Committee for an opinion. They stated:

"As you point out the Code contains no rules referring directly to the qualification of machine welding. However, machine welding has been widely used in the construction of Code vessels and I believe that it is the practice of fabricators to qualify their welding procedures by following the details given in Section IX in so far as applicable. It is my understanding that it is customary to work out the details of procedure qualification with the authorized inspector and such procedure shall have his approval."

Since the operator follows an established procedure in setting current amperage and voltage, etc., we assumed operators would not have to be qualified, however, in Case 1046, "Interpretations of A.S.M.E. Boiler Code," the Commiteee adds:

"It is the opinion of the Committee that for automatic welding processes, each machine operator (the term "operator" is used to designate the person having final control of any adjustments) shall make procedure qualification test plates of the maximum thickness to be used, of similar material (killed, semikilled, or rimmed), and the same machine setting. The test plates shall be tested and meet the requirements of Section IX, Pars. P-102, L-102 and U-68 for the type of vessel to be constructed."

Since our positioning equipment limited use of the welding machine to outside of joint we are developing an attachment for inside welding. The welding machine is to be used on the present positioning equipment and is provided with a fillet weld attachment which will feed welding wire at an angle to welding head. A flexible tube is secured to the fillet weld attachment in a way so wire is driven from head through fillet attachment and into the flexible tube. The tube directs the wire to a set of contactors which position it properly in reference to joint. The contactors, a flux hopper, and tube, are mounted on a set of guiding and supporting rolls. The contactors are connected to welding machine and current adjustments, etc., are obtained as in normal operation. With this attachment we have a flexible means for inside work that is small and adapts the present machine to this purpose. The attachment necessarily uses small diameter wire to retain flexibility. Girth seams are welded by holding attachment in a given position radially, guide rolls lead wire and flux deposit to proper location in groove and drum is rotated providing the predetermined travel speed. Longitudinal seams are similarly welded but attachment travel is controlled by steadying manually and by running welding head in direction of welding on the traversing beam, giving a uniform travel speed to flexible tubing, connecting cables and inside attachment. This device is experimental and as yet we have not used it in production. Successful use of attachment depends entirely on operator's judgment of speed and ability to maintain a given position. These qualities will be developed by the operator on continued use of machine with attachment.

Typical examples of equipment with butt joints in pressure parts as an important means of fabrication are shown in Figs. 10, 11, 12 and 13. Figure 10 illustrates a Yarrow type boiler of which design and complete specifications were furnished by the purchaser. Upper drum diameter 54 in., lower drums 24 in. Figure 11 illustrates a Union Dowtherm Generator. Furnace is completely Dowtherm cooled. Upper drum diameter 30 in., lower drum 24 in. Figure 12 illustrates a Union "S" type Steam Generator. Furnace has water-cooled side walls. Side wall headers are fillet welded inside and out to front heads of lower drums. Upper drum diameter 42 in., lower drums 28 in. Figure 13 illustrates a fired pressure vessel, the furnace and vessel being integral parts of the unit. The lower head and longitudinal joints of vessel are radiographically inspected because they are subjected to primary gases of combustion and thermal shock which occur on heating and cooling. Vessel operates at a comparatively low pressure not requiring this inspection but it is our assurance to purchaser of equipment that the most stressed seams are of sound structure.

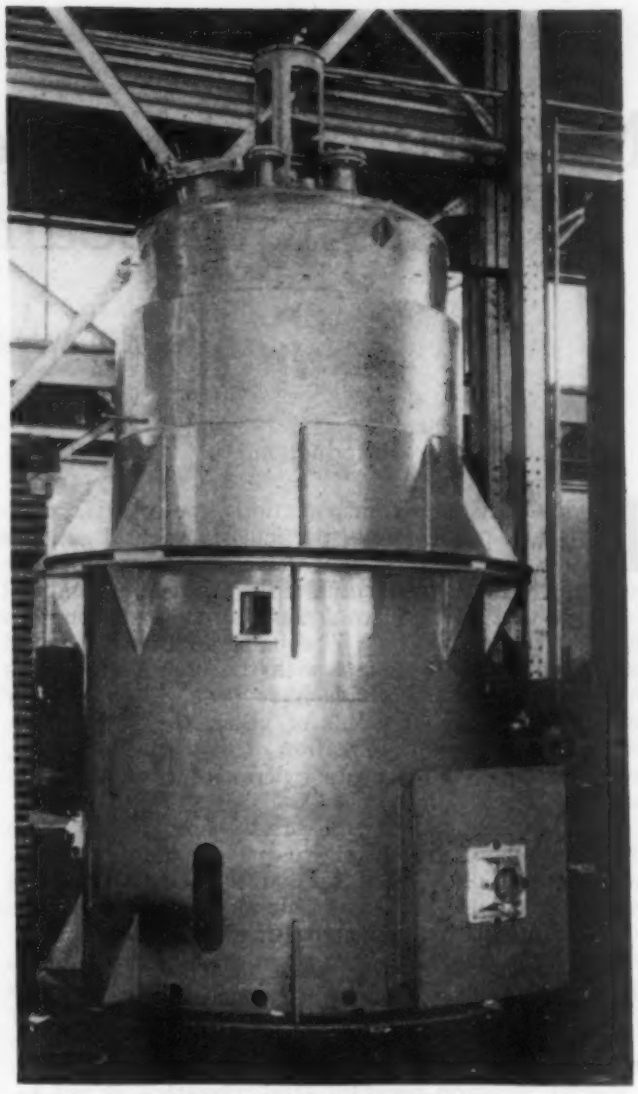


Fig. 13—Fired Pressure Vessel

Metallurgical Properties of High Yield Strength Seamless Line Pipe*

By A. B. Wilder† and J. D. Tyson‡

Introduction

LONG distance transportation of petroleum, petroleum products and particularly natural gas, has in recent years created a vast network of pipe lines which are the connecting links between our natural resources and the industrial centers of population. In the relatively near future, a probable additional demand for pipe lines will originate with the production of gas from coal. Although fluids have been conveyed over long distances for hundreds of years, the large transmission pipe line is the creation of modern civilization, and we are now embarking on a period of its greatest usefulness.

Steel has been almost universally used for pipe-line construction and one of the most important developments in the application of this material has been the field welding of joints. It is the generally accepted practice to weld line pipe without preheating, postheating or the use of a back-up strip. Such practice, however, requires a proper steel and welding technique. After the pipe has been welded, it is frequently coated with a bitumastic or other material to prevent soil corrosion. Anodic protection of the pipe may also be used to inhibit corrosion. A special corrosion resistant steel, therefore, is not required in pipe-line construction as other methods have been developed for protecting the outside and inside surfaces of the pipe.

In addition to providing a suitable material for welding, it is also important to consider the tensile properties of the steel. A problem of this type involves a consideration of the yield strength of the material which has an important economic bearing not only in the design of the pipe line, but also in the manufacture of the material. A high yield strength steel not only permits the use of lighter wall pipe, but also higher working pressures. If an expensive alloy steel is used to obtain higher physical properties, then the economic advantages of the material may be lost. Further, the yield strength is limited by welding requirements. Therefore, in providing a high yield strength material, the manufacturer must either utilize the full benefits to be derived from the addition of suitable chemical elements to the steel or resort to other methods for improving this property.

Under suitable welding conditions, it has recently been developed that steel melted to 0.40% max. carbon and 1.40% max. manganese with a minimum yield strength of 52,000 psi. may be used for pipe lines. A steel of this type may be economically produced in large diameter seamless pipe. This should be compared with steel melted to 0.30% max. carbon and 1.25% max. manganese with a minimum yield strength of 42,000 psi. which is commonly used for line pipe. Naturally, a steel with higher chemistry requires a different welding technique, but a steel of this type provides a joint that possesses inherent physical properties after welding which are closely related to the chemistry of the original material.

Pipe for oil or gas transmission lines is often machined on the ends with a 30° bevel and a $^1/_{16}$-in. face. Joints are usually lined up, and tack welded, but if an internal line-up clamp is used, the necessity of tack welding is eliminated. In the manual metallic arc welding of light wall line pipe, usually a root bead, one or two filler beads and a cover bead are used. Defects in a weld of this type are usually localized and, therefore, the strength of the joint is maintained. All-position welding is frequently used, and multiple passes have the effect of heat treating the deposited metal except for the last pass which is the cover bead. When pipe bends in the line are required, the main body of the pipe may be hot or cold bent so that the weld is not subjected to this treatment. In this investigation, manual metal arc welding was employed, although other types of welding have been used in the field. Due to the fact that only seamless pipe was considered, the problems encountered in girth welding were studied.

Purpose of Investigation

This investigation involves a study of the properties of a new grade of seamless line pipe with a 52,000 psi. minimum yield strength and 75,000 psi. minimum tensile strength. In the manufacture of the seamless pipe, the approach to these requirements involved the use of carbon and manganese. Due to the fact that current practice in the manufacture of seamless line pipe has been limited to 0.30% max. carbon, 1.25% max. manganese with a minimum yield strength of 42,000–45,000 psi. (depending on the wall thickness), the application of seamless pipe with a minimum yield strength of 52,000 psi. involves a number of problems due to appreciable increase in strength characteristics.

Upon the basis of extensive experience in the production of seamless casing with a minimum yield strength of 55,000 psi., it was concluded that the physical property requirements of the new grade of seamless line pipe could be obtained by melting steel to 0.40% max. carbon, 1.40% max. manganese. Steel of this type was successfully rolled into 26-in. diameter seamless pipe and satisfactory tensile properties were obtained. An evaluation of the metallurgical properties of the material remained to be determined and it is only this phase of the work which will be discussed. Although other interesting problems were encountered in the manufacture of this new grade of steel, the user is primarily interested in the properties of the material, particularly with regard to welding.

* Scheduled for Twenty-Eighth Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 19, 1947.

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Table 1—Chemical and Physical Properties of the Steel Tested

Code No.	Type	Process	C%	Mn%	P%	S%	Si%	Yield 1000 Psi.	Ultimate 1000 Psi.	% Elongation in 2 In.
A	26-in. O.D. x 0.303-in. wall pipe	O.H.	0.36–0.39	1.24–1.28	0.014	0.033	..	55–69	86–100	27–35
B	18-in. O.D. x 0.312-in. wall pipe	O.H.	0.38	1.42	0.010	0.023	0.24	65	98	28
C	20-in. O.D. x 0.312-in. wall pipe	O.H.	0.22	0.47	0.008	0.022	..	43	64	42
D	26-in. O.D. x 0.303-in. wall pipe	O.H.	0.30	1.12	0.011	0.023	..			
E	26-in. O.D. x 0.303-in. wall pipe	O.H.	0.31	1.26	0.011	0.022	..			
F	26-in. O.D. x 0.303-in. wall pipe	O.H.	0.36	1.14	0.009	0.021	..			
G	26-in. O.D. x 0.303-in. wall pipe	O.H.	0.37	1.36	0.010	0.026	..			
H	0.303-in. gage plate	I.F.	0.32	1.35	0.016	0.027	0.08			
I	0.303-in. gage plate	I.F.	0.37	1.37	0.016	0.027	0.08			
J	0.303-in. gage plate	I.F.	0.41	1.16	0.015	0.026	0.05			
K	0.303-in. gage plate	I.F.	0.40	1.34	0.016	0.025	0.07			
L	0.303-in. gage plate	I.F.	0.40	1.42	0.011	0.019	0.09			

O.H.—basic open hearth.
I.F.—induction furnace.

Table 2—Chemical and Physical Properties of the Weld Metal

Electrode	Typical Analysis of Deposited Metal C%	Mn%	Si%	P%	S%	Mo%	V%	Cr%	Yield 1000 Psi.	Ultimate 1000 Psi.	% Elongation in 2 In.
(U) E6010	0.10–0.14	0.40–0.55	0.01 max.	0.030 max.	0.035 max.	.....	.....	..	53–60	65–77	22–30
(V_1) E7010	0.09–0.13	0.50–0.65	0.10	0.035 max.	0.035 max.	0.50–0.55	.....	..	62–66	77–82	18–25
(V_2) E7010	0.08	0.70	0.28	0.019	0.015	0.48	.....	..	62–70	73–85	20–25
(V_3) E7010	0.07	0.34	0.15	0.017	0.022	0.52	.....	..	57–63	72–80	25–28
(W) E8011	0.11	0.34	0.19	0.012	...	0.52	.....	0.54	73–75	88–90	19–20
(X) E10010	0.09–0.13	0.50–0.65	0.10	...	...	0.70–0.85	0.10–0.15	..	90–100	103–112	14–17

In order to develop metallurgical information concerning the behavior of the new material under welding conditions, the influence of welding technique was explored. This involved a study of various types of weld rod combinations and weld bead sequence in girth welds. A range of chemistry was explored. In addition, tensile tests, bend tests, microstructure, hardness surveys, X-ray examinations and weld bead tests were studied.

Materials

The chemical and physical properties of the various steels used in this investigation and the type of material tested are shown in Table 1. Chemical and physical properties of the weld metal in the as-welded condition are shown in Table 2. Electrodes V_1, V_2 and V_3 although of the same type, were of different manufacture. All of the open-hearth steels were tested in the as-rolled condition and the induction furnace heats were normalized.

The chemical and physical properties of approximately 350 160-ton heats of steel, which have been rolled into 26-in. O.D. x 0.303-in. wall line pipe, are as follows:

	Specification	Actual Range
Carbon	0.40% max.	0.30–0.39%
Manganese	1.40% max.	0.94–1.36%
Phosphorus	0.040% max.	0.007–0.027%
Sulphur	0.050% max.	0.017–0.047%
Alloys		Residual
Yield strength, psi.	52,000 min.	53,500–74,000
Ultimate strength, psi.	75,000 min.	79,400–100,000
Elongation in 2 in.	22%	22.5–38.0%

The 26-in. O.D. x 0.303-in. wall line pipe used in this investigation was selected from the above heats. The other types of material tested were melted on the basis of chemistry, as all of the regular production heats had not been melted at the time of the experimental program.

Testing Methods

Girth Welds

Circumferential welding of full pipe sections was used in this investigation. The pipe was rotated and manual metallic arc welded with coated electrodes in a downhand position. After tack welding a root or stringer bead was applied, followed by a filler bead and finally a face or cover bead. The type of joint and welding sequence are shown in Fig. 1. Possible modifications of the welding sequence described in Fig. 1 are indicated elsewhere in this investigation. Except where noted, the girth welds were not preheated, post heated or stress relieved.

Weld Bead Tests

In order to reduce the variables associated with manual metallic arc welding, weld bead tests shown in Fig. 1 were made at the U. S. Steel Corp. Research Laboratory. These beads were deposited with an automatic welding head with a stick electrode attachment. As may be noted from Fig. 1, two single weld beads were deposited on each steel specimen. One bead, 6-in. in length, was deposited using a $^3/_{16}$-in. diameter electrode with 180 amp. and 9-in. per minute travel speed. The plate was at 80° F. prior to deposition of this bead. A second bead, 3-in. in length, was deposited using a $^5/_{32}$-in. diameter electrode with 170 amp. and 17-in. per minute travel speed. The plate was cooled to 32° F. prior to deposition of this bead. The reason for depositing two beads of such widely different characteristics was to represent (1) nor-

mal or average welding practice and (2) the most unfavorable welding conditions that might be encountered, particularly in tack welding. An E-7010 welding rod was used for both beads. A transverse section of the weld bead test was examined and the microstructure and hardness evaluated. A longitudinal section of pipe was also used so that the beads would be deposited under conditions similar to the plate specimens.

Tensile and Bend Tests

Tensile tests of the original pipe and plate material were conducted in accordance with Specification API 5-L. The tensile test specimen for unwelded pipe or plate is shown in Fig. 2. Tensile test specimens of welded pipe sections are also shown in Fig. 2 and, except where noted in the investigation, excess weld metal was not machined from the specimen. Although tensile test strip

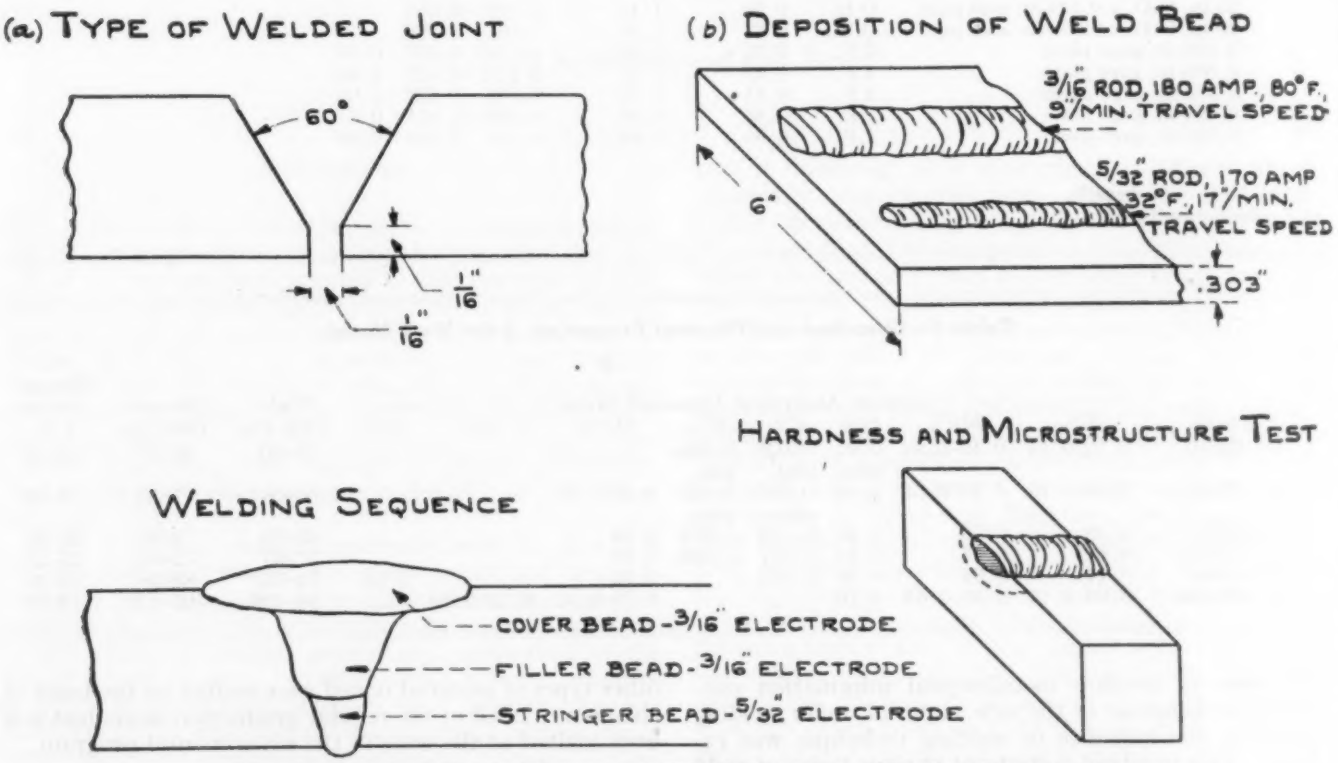


Fig. 1—Type of Welded Joints and Weld Bead Tests Used in Investigation

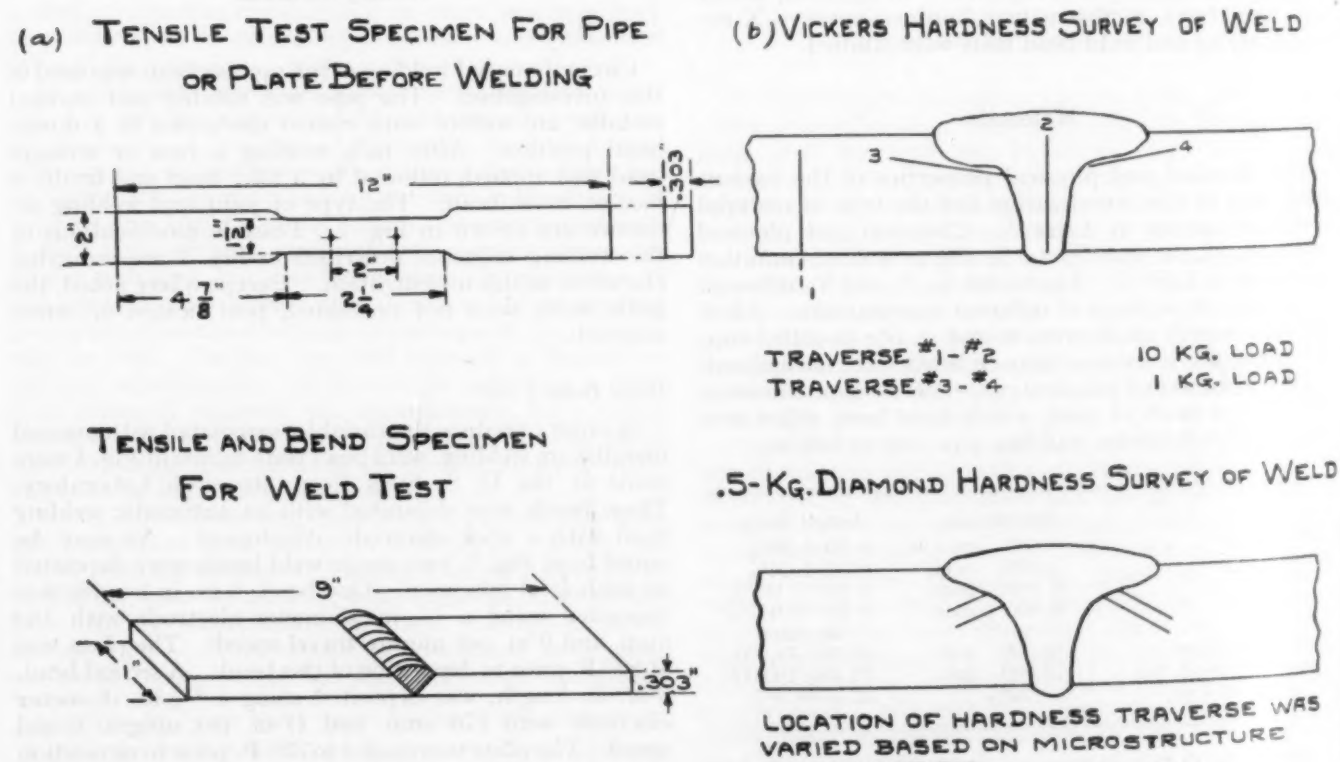
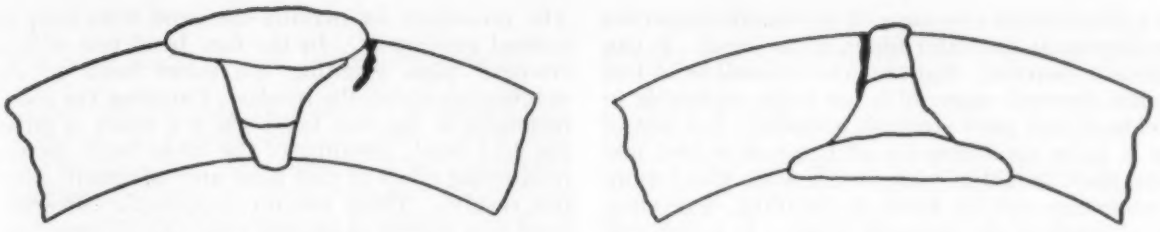


Fig. 2—Tensile, Bend and Hardness Test Specimens



CRACK IN FACE BEND TEST CRACK IN ROOT BEND TEST

Fig. 3—Typical Failures in Bend Tests

specimens from welded pipe are usually prepared by oxy-acetylene flame cutting, in this investigation the specimens were machined from the pipe.

A guided bend test with a $^5/_8$-in. radius plunger was used. Except where noted in the investigation, the guided bend test specimens were similar to the tensile test specimens of the welded pipe sections shown in Fig. 2. In the bend test, pressure was applied in a tensile testing machine until a crack appeared or until completion of a 180° bend. Since the $^5/_8$-in. radius plunger was smaller than the A.W.S. standard $^3/_4$-in. radius plunger, the bends made in these experiments can be considered more severe than the standard guided bend test. Although the influence of aging on bend test results is frequently considered significant, this factor was not evaluated.

Hardness Tests

The Vickers hardness tests were conducted with a 1- and 10-kg. load on a standard Vickers hardness tester. Caution was exercised in applying a suitable load during testing because of inertia effects in the machine. In addition to these tests, hardness determinations with a 0.5-kg. load were made by the U. S. Steel Corp. Research Laboratory. A transverse test specimen selected from the weld was polished for hardess testing. The specimen was machined from the welded pipe or plate section so as to eliminate any effects from heating. The locality of hardness surveys is shown in Fig. 2.

In determining the maximum hardness of a weld, considerable care must be exercised to secure satisfactory results. The U. S. Steel Corp. Research Laboratory developed the 0.5-kg. load hardness testing machine used in this investigation. This machine, referred to as "Intermediate DPH Tester," comprises an indenting mechanism, a mechanical stage for holding the specimen, a microscope for locating the test field and measuring the impression, and a control box for automatically spacing the impressions. The reading error in the range of hardness investigated with a 0.5-kg. load is less than 1%. The error in hardness number for this reading error is not more than ±2%.

Other Tests

X-ray examination of welded pipe joints was conducted with a 185,000 volt X-ray machine and radiographs of the complete welds were made. Any indications in the radiographs of cracks or other defects in the weld were confirmed by metallographic examination.

Metallographic examination of the weld heat-affected zone base metal and the base plate was conducted on a transverse weld section which was also used for hardness testing. Weld specimens were machined from the pipe in order to eliminate the possible heat effect of flame cutting.

Bend Test Technique

In welding pipe lines, the bend test is frequently used for qualification of welders and as a control test. The welders must be familiar with proper adjustment of welding current, securing proper penetration and control other factors in order to achieve satisfactory results. Although a guided 180° bend over a $^3/_4$ in. radius is the standard test and is frequently considered a satisfactory qualification or control test for line pipe welders, it has not been shown that a bend of this severity is necessary for line pipe service.

A weldment of 52,000 psi. minimum yield strength material should not be expected to have the same bending properties as a weldment of 35,000 psi. minimum yield strength material due to the difference in minimum elongation. In addition to its intended function of indicating the defects that may be present in the weld, the bend

Table 3—Bend and Tensile Test Results of Welded Pipe

Treatment	Weld Rod	Face Bend No. of Bends	Face Bend Angle	Root Bend No. of Bends	Root Bend Angle	Tensile Yield 1000 Psi.	Tensile Ultimate 1000 Psi.	Tensile % Elongation in 2 In.
26-In. O.D. x 0.303-In. Wall (0.36–0.39% Carbon, 1.24–1.28% Manganese Steel)								
Unground	(1)	6	135°	6	160°	68	91	22
Cover bead ground flush	(1)	6	170°	.	..			
Root bead ground flush	(1)	.	..	6	175°			
Cover bead and root bead ground flush	(1)	3	180°	3	140°			
20-In. O.D. x 0.312-In. Wall (0.22% Carbon, 0.47% Manganese Steel)								
Unground	(2)	6	180°	6	180°	46	66	29
Cover bead ground flush	(2)	6	180°	.	..			
Root bead ground flush	(2)	.	..	6	180°			

(1) Rod combination: V$_3$—E7010 (root), W—E8011 (filler), W—E8011 (cover).
(2) Rod combination: U—E6010 (root), U—E6010 (filler), U—E6010 (cover).

test is to a great extent a measure of the ductile properties of the weldment at the outer fibers of the bend. It can be recognized, therefore, that the conventional bend test for low yield strength material is not truly applicable to sound welds of high yield strength material. If a test of this type is to be applicable for all types of welded line pipe joints, there should be some modification which more clearly recognizes varying levels of ductility, depending upon the strength of the material tested. It is believed that a practical approach to such a modification would be to vary the radius of the bend test so that the maximum elongation in making a 180° bend would be proportional to the expected elongation of the material welded. In the standard bend test, the types of failures usually encountered are shown in Fig. 3.

The cover bead in the tensile test of line pipe welds reinforces the weld and strengthens the heat-affected zone, but is detrimental in the bend test, due to stress concentration associated with the notch effect. Lack of proper penetration or excess weld metal in root bead also develops a notch effect which is harmful. In order to evaluate this situation, a number of special bend tests were performed.

In Table 3, bend and tensile test results obtained with various types of specimens in 26-in. O.D. x 0.303-in. wall high yield strength pipe and 20-in. O.D. x 0.312-in. wall, 35,000 psi. minimum yield strength pipe are summarized. The procedure for making the bend tests have been described previously. In the face bend test of high yield strength pipe, grinding the cover bead to eliminate notches improved the results. Grinding the root bead is beneficial in the root bend test if a notch is present. In the root bend, grinding of the cover bead decreased the reinforcing effect of this bead and adversely affected the test results. There was no appreciable difference in the bend test results of normal yield (35,000 min. psi.) pipe. The tests reported in Table 3 were made on machine-cut specimens.

Influence of Preheat, Postheat and Pipe Temperature

Although ordinary line pipe is not preheated or postheated during welding, pipe temperatures may vary. The effect of these variables on tensile and bend test results are reported in Table 4. Three specimens were used for each test. The test specimens were milled and the bead, under tension in bending, was ground flush with pipe surface. Preheat had little effect on the bend test results due to the loss in temperature during welding. Postheat showed possible improvement in bend test results and this may indicate the metallographic structure adjacent to the cover bead is affected by the post-heat treatment and the residual stresses may be more completely removed. No appreciable differences in bend

Table 4—Influence of Preheat, Postheat and Pipe Temperatures When Welding 0.36–0.39% C, 1.24–1.28% Mn Steel

Heat Treatment	Weld Rod	Face Bend Angle	Root Bend Angle	Weld Tensile Tests: Yield 1000 Psi.	Ultimate 1000 Psi.	% Elongation in 2 In.
Cooled to 25° F.	(1)	150°	180°	74	93	29
Cooled to 25° F.	(3)	180°	180°	75	89	10
None (70° F.)	(1)	160°	180°	68	91	22
None (70° F.)	(2)	160°	180°	79	94	10
None (70° F.)	(3)	180°	180°	74	97	15
Preheat 250° F.	(1)	160°	180°	75	90	12
Preheat 250° F.	(3)	160°	180°	73	94	15
Preheat 600° F.	(1)	140°	155°	72	92	13
Preheat 600° F.	(2)	130°	170°	74	94	13
Postheat 1000° F.	(1)	180°	180°	69	93	17
Postheat 1000° F.	(2)	180°	180°	66	85	9

(1) Rod combination: V_3—E7010 (root), W—E8011 (filler), W—E8011 (cover).
(2) Rod combination: V_2—E7010 (root), X—E10010 (filler), X—E10010 (cover).
(3) Rod combination: V_1—E7010 (root), X—E10010 (filler), X—E10010 (cover).

Table 5—Effect of Various Welding Rod Combinations on Bend and Tensile Tests of 0.36–0.39% C, 1.24–1.28% Mn Steel

Type of Weld Rod: Root	Filler	Face	Root Bend Angle*	Face Bend Angle*	Weld Tensile Tests: Yield 1000 Psi.	Ultimate 1000 Psi.	% Elongation 2 In.
U	U	U	180°	180° (b)	63	89	9
X	U	U	180°	115°	74	89	9
U	X	U	180°	90°	72	97	17
Z	X	U	180°	70° (a)	75	102	17
X	X	X	180°	180° (b)	73	97	15
U	X	X	165°	130°	70	100	17
X	U	X	180°	170° (b)	71	94	21
U	U	X	180°	165°	70	84	8
V_2	V_2	V_2	180°	85°	72	93	21
W	W	W	180°	170° (b)	73	95	18
V_3	V_3	V_3	180° (b)	150°	62	88	16
V_2	X	X	180°	165°	72	98	16
V_2	W	W	170°	160°	65	95	16
V_1	X	X	180°	170°	76	95	16

* All results represent an average of three tests except (a) 1 test, and (b) 2 tests.
Rod type: U—E6010, V_1—E7010, V_2—E7010, V_3—E7010, W—E8011, X—E10010.

test results were found in pipe temperatures of 25° to 250° F.

In pipe-line welding, the root bead is generally subjected to the greatest cooling rate and, therefore, is most susceptible to cracking. This bead, however, is subject to a tempering treatment resulting from deposition of the filler bead. The filler bead receives a similar treatment when the cover bead is deposited. The cover bead does not receive the beneficial effects of a tempering treatment. In the bend test, the surface contour of the cover bead produces a notch effect and the area at the notch is subjected to the greatest stress concentration. Therefore, in a sound weld, the face bend is more generally susceptible to failure.

Results with Various Types of Weld Rod Combination

In the welding of ordinary line pipe, a low tensile rod such as E6010 is generally used. The cover bead with reinforcement not only strengthens the cross section of a weld in the tensile test, but, in addition, is responsible for a special type of stress distribution developed in the bend test. Therefore, not only the strength characteristics of the weld metal, but the type of weld beads, particularly the face bead, are significant.

Special consideration with reference to bend test results, should be given to the weld rod combination used in the welding of high yield strength line pipe. The shape of the weld beads used for high yield strength line pipe

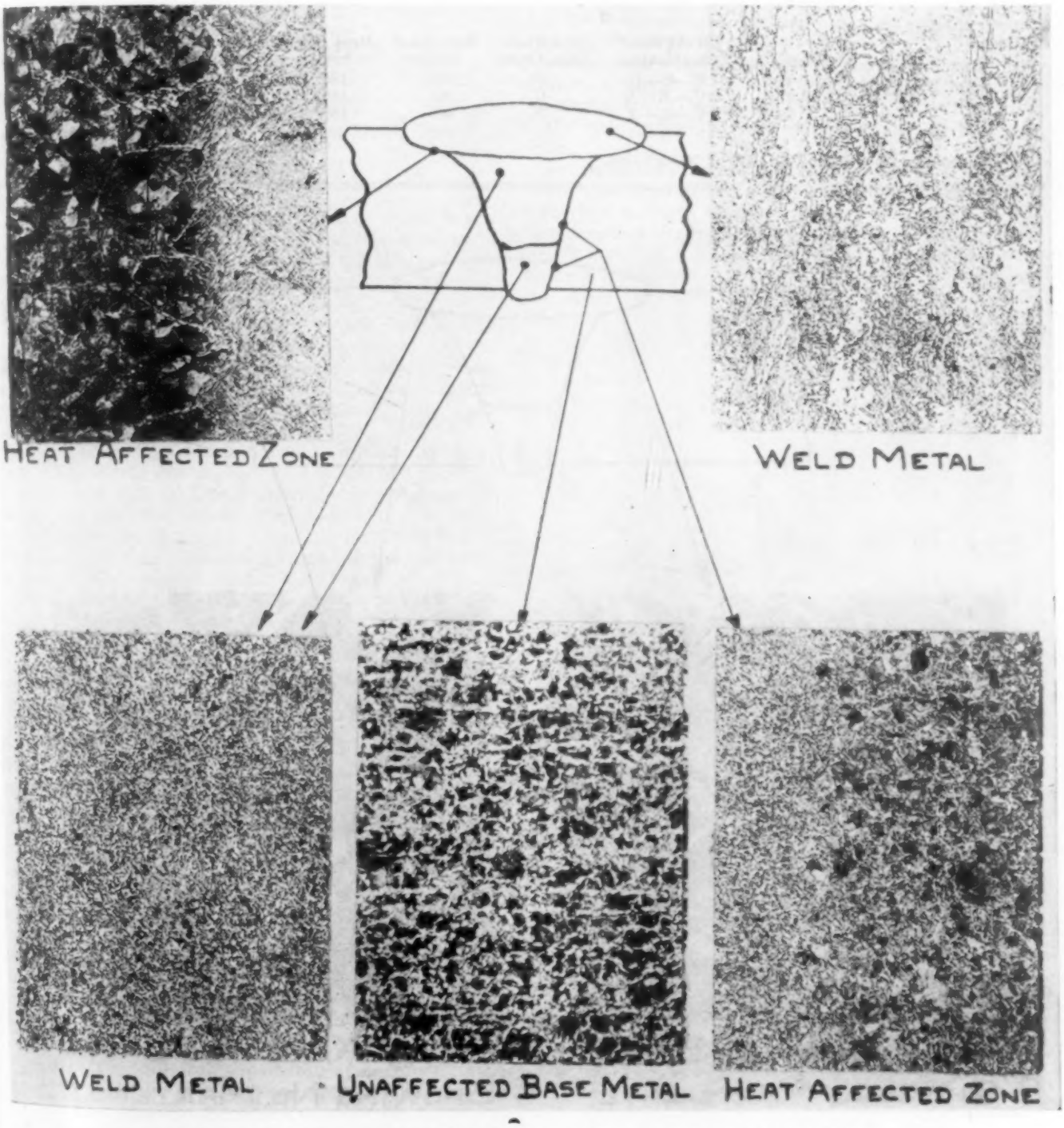


Fig. 4—Microstructure, Girth Welds. 100 ×. Etchant, Picrol-Nital

welds (Fig. 1) were similar to the practice used for ordinary line pipe. In this investigation, various weld rod combinations were studied and the results are summarized in Table 5. The test specimens were milled and the bead, under tension in the bend test, was ground flush with the pipe surface.

All of the weld rods were coated. The lime base coated rod was not included since additional development work is necessary before this rod is applicable to all-position welding. The influence of hydrogen on the cracking susceptibility of steel is recognized and, although the commercial aspects of the low hydrogen rod place certain restrictions on its use in line pipe welding, the technical significance of this development is of general interest.

It will be noted in Table 5 that little difference was observed in the root bend tests with various types of weld rod combinations. Variation in the face bend results were obtained. Although the E6010-E6010-E6010 rod combination resulted in satisfactory bends, the weld yield strength and elongation were low and all tests broke in the weld. Whenever more than one bead of E6010 rod was used, the weld tensile test elongation was generally low. It is interesting to note that whenever a

Table 6—Influence of Chemistry on Tensile and Bend Tests

Code No.	C%	Mn%	Weld Rod* Combination	No. Tests Each Group	Face Bend Angle	Root Bend Angle	Weld Tensile Tests: Yield 1000 Psi.	Weld Tensile Tests: Ultimate 1000 Psi.	Weld Tensile Tests: % Elongation in 2 In.
C	0.22	0.47	U—U—U	6	180°	180°	46	66	29
A	0.37	1.27	V_1—X—X	6	165°	180°	74	98	19
B	0.38	1.42	V_1—X—X	5	149°	180°	90	105	16

* Welding rods: U—E6010, V_1—E7010, X—E10010.

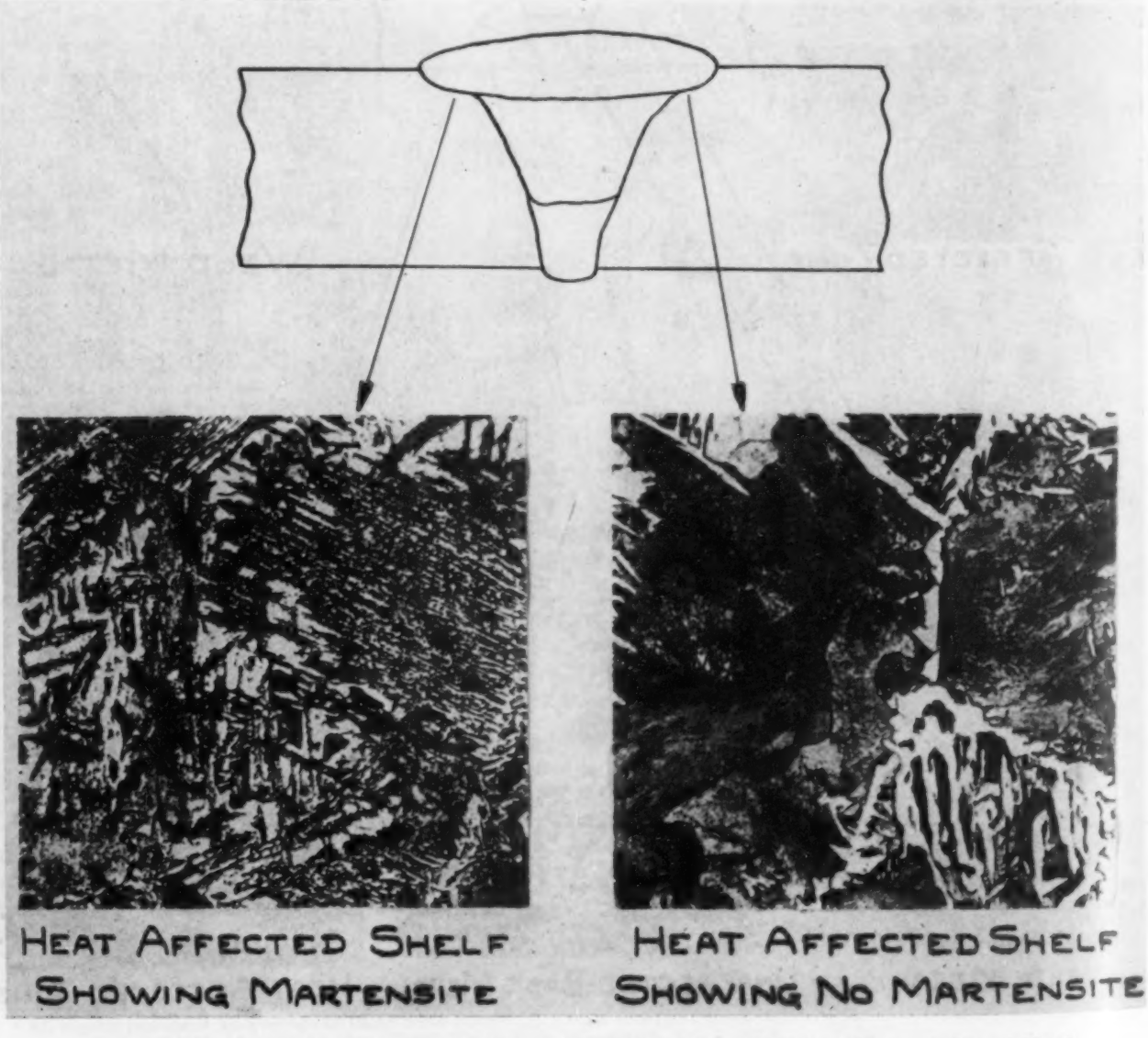


Fig. 5—Microstructure Showing Martensite-Girth Welds. 1000 ×. Etchant, Picrol-Nital

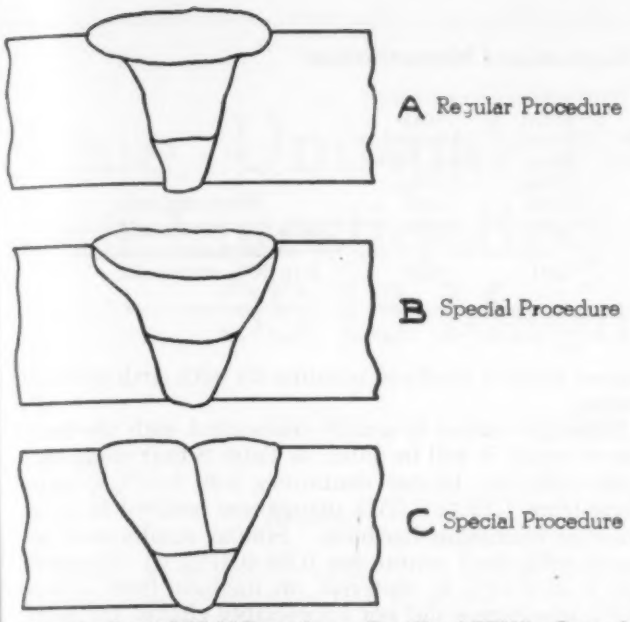


Fig. 6—Special Weld Procedure. Root Bead E7010. Second and Third Beads E10010

high-strength rod is used in either the first or second beads and covered with a soft E6010 rod, the face bend tests were generally poor. For these reasons, a higher strength rod than E6010 was used for the grade of steel under investigation.

The results with relatively high-strength rods E10010 or E8011 in all three beads were slightly superior to the use of an E7010 rod for the root bead, followed by two beads of either E10010 or E8011 rods. These combinations appeared to be preferable to the use of E7010 rods for all three beads.

In addition to the bend test results, it is significant to observe the tensile test results. The tensile test fractures of those weld rod combinations which showed improvement in the bend tests, were usually located in the unaffected base plate. With the use of a high strength weld rod combination and excess weld metal in the face bead, the tensile properties of welded high yield strength line pipe, with the exception of the elongation, should be essentially dependent upon the strength of the base plate material. The bend test results, due to their relationship to ductility and welding technique of individual welders, are subject to greater variation in the welding of high yield strength line pipe.

Tests of this type do not evaluate the material with regard to cracking susceptibility in the same manner as a radiograph of the weld. Radiographic tests were conducted and are described later.

The weld rod combination used in the field welding of high yield strength line pipe is particularly significant with reference to conventional tensile and bend test results. In addition, the welding technique, particularly with reference to the skill of the welder, should be recognized. Not only does the nature of the face bead exert an influence on the test results obtained, but the technique in applying the root bead is particularly significant.

Influence of Chemistry on Girth Welds

A number of girth welds made in accordance with the procedure described in Fig. 1 were examined in order to evaluate the influence of chemistry on the structure and properties of the welded pipe joint. The bend and tensile test results are shown in Table 6. It will be noted that the bend tests in ordinary line pipe, Code C (Grade B—20-in. O.D. x 0.312-in. wall) were 180°. The tensile tests corresponded to the grade of steel involved and the specimens broke in the base plate.

The 26-in. O.D. x 0.303-in. wall pipe (Code A) with a chemistry of 0.37% carbon, 1.27% manganese had root bends which withstood 180° bend, but several failures occurred in the face bend tests, although the average angle of bend was nearly 180°. The yield and ultimate strengths of the weld tensile tests were much higher compared to ordinary Grade B line pipe material, due to the higher chemistry pipe and weld rod. The elongation was lower and the tensile tests usually fractured in the base plate, although in two instances fracture occurred in the weld.

The 18-in. O.D. x 0.312-in. wall pipe (Code B) had bend and tensile tests similar to the 26-in. O.D. x 0.303-in. wall pipe. The higher chemistry of the 18-in. O.D. pipe was responsible for the lower average angle of bend, although the angle of bend was nearly 180°. The high chemistry was responsible for the increased yield and ultimate strength of the weld tensile test, but decreased the elongation. Two of the weld tensile tests fractured in the weld, while the remainder fractured in the base plate.

The hardness survey made in accordance with the procedure described in Fig. 2 and microstructure of several high yield strength welds are shown in Table 7. It will be noted that the maximum diamond pyramid hardness (10-kg. load) of the heat-affected zone was 357 and the maximum diamond pyramid hardness (0.5-kg. load) of the same zone was 452 in the high chemistry weld. Martensite was observed only in the shelf associated with the face bead of the highest chemistry weld. No cracks were observed in the hardened structure. The presence of martensite was associated with the shape of the face weld bead and the fact that this bead is not heat treated as the filler bead or root bead. The martensite area is

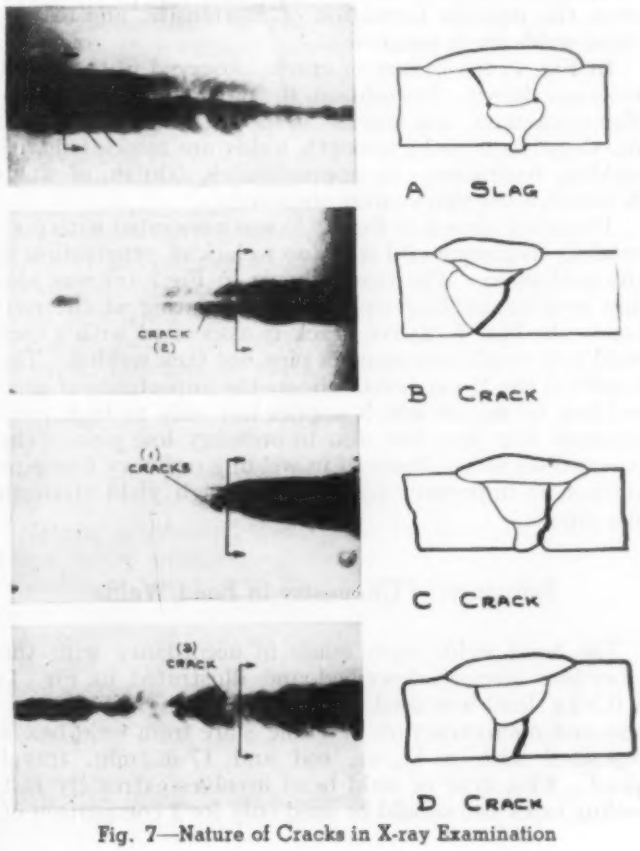


Fig. 7—Nature of Cracks in X-ray Examination

Table 7—Influence of Chemistry on Hardness and Microstructure

Code No.	C%	Mn%	No. of Tests	DPH Hardness: Unaffected Base Metal, Max. 10-kg. Load	DPH Hardness: Heat-Affected Zone, Max. 1-kg. Load	DPH Hardness: Weld Metal, Max. 10-kg. Load	DPH Hardness: Heat-Affected Zone, Max. 0.5-kg. Load	Microstructure
A	0.35	1.26	8	207	266	210	258	Pearlite, bainite and ferrite without any martensite
B	0.38	1.42	4	223	357	230	452	2 to 20% martensite

Table 8—Influence of Chemistry on Bead Welds

Code	C%	Mn%	Max. Hardness,* DPH	Microstructure at Max. Hardness
D	0.30	1.12	426	Martensite—90%
E	0.31	1.26	499	Martensite—90%
H	0.32	1.35	534	Martensite—99%
F	0.36	1.14	407	Martensite—85%
G	0.37	1.36	508	Martensite—90%
I	0.37	1.37	553	Martensite—99%
J	0.41	1.16	572	Martensite—95%
K	0.40	1.34	627	Martensite—99%
L	0.40	1.42	583	Martensite—99%

* 0.5-kg. load.

well surrounded with more ductile material and is not associated with mechanical stress raisers. Typical microstructures are shown in Figs. 4 and 5, and it will be noted that the weld metal and heat-affected zone of the cover bead differ from the filler or root bead.

Due to the nature of the hardness results which were associated with the shelf of the face bead, different methods for depositing the weld beads are suggested. In Fig. 6, two special procedures are proposed which may reduce the possible formation of martensite, and tests of these welds are in progress.

In Fig. 7, the nature of cracks observed in the X-ray tests are shown. In addition, the nature of occurrence of slag pockets or "car tracks" is shown. Cracks observed in, these high yield strength welds are associated with welding technique. In approximately 500 in. of welds X-rayed, a few cracks were observed.

The crack shown in Fig. 7 (*b*) was associated with poor welding technique and was due to lack of penetration in the root bead. The crack shown in Fig.7 (*c*) was also due to poor welding technique, originating at the root bead. In Fig. 7 (*d*) the crack is associated with a tack weld and would not occur in pipe not tack welded. The results of the X-ray tests indicate the importance of good welding technique which applies not only to high yield strength line pipe, but also to ordinary line pipe. The precautions to be observed in welding ordinary line pipe are not as important compared to high yield strength line pipe.

Influence of Chemistry in Bead Welds

The bead welds were made in accordance with the procedure already described and illustrated in Fig. 1. A 0.5-kg. load was used in hardness testing. The hardness and microstructure in Table 8 are from weld beads deposited with a $^5/_{32}$-in. rod and 17-in./min. travel speed. This type of weld bead involves extremely fast cooling rates and should be used only for a comparison of various types of steel and not directly with girth weld test results.

Although carbon is usually associated with the hardness of welds, it will be noted in Table 8 that manganese is also a factor. In steel containing 0.30–0.32% C an increase from 1.12 to 1.35% manganese resulted in an increase in maximum hardness. Similar results were obtained with steel containing 0.36–0.37% C. However, with 0.40–0.41% C material, an increase from 1.16 to 1.42% manganese did not appreciably change the maximum hardness obtained due to the high carbon content of the material. These results indicate that under certain conditions, it may be more desirable to increase the carbon content in preference to manganese in order to secure higher yield strength material. A closer relationship to the conditions encountered in girth welds will be obtained when results from tests being conducted with a $^3/_{16}$-in. rod and 9-in./min. travel speed are available. In line pipe welding, carbon has usually been considered the most important factor with respect to the maximum hardness obtained in the weld. These results indicate that under certain conditions, manganese may be the controlling factor.

Summary

1. Various factors relating to the bend tests in high yield strength line pipe were investigated. Removal by grinding of the mechanical notch effect of the outside bead improved the ductility of the welded joint as measured by the bend test.

2. Various types of weld rod combinations and their influence on the physical properties of the welded joint were investigated. High strength weld rod combinations involving Types E7010, E8011 and E10010 electrodes produced the best results for high yield strength line pipe.

3. The influence of chemical composition of pipe material on the physical properties of welds in high yield strength line pipe was evaluated, and the relationship of carbon and manganese developed. A minimum yield strength of 52,000 psi. and minimum tensile strength of 75,000 psi. were obtained with open-hearth steel pipe containing 0.40% max. carbon and 1.40% max. manganese.

4. Results with X-ray analysis of girth welds in high yield strength line pipe indicated the importance of proper welding technique.

Acknowledgment

The authors appreciate the help received from the management and operating personnel of National Tube Co. in carrying out the experimental results of this investigation. The personnel and facilities of the U. S. Steel Corp. Research Laboratory contributed much to this investigation.

Some Unusual Features Encountered in Investigating Cracked Welds in 35/15 Magnesium Retorts*

By H. J. Nichols†

Summary

HIGH alloy castings of the H.T. (Alloys Castings Institute designation)type have long been popular for high temperature service. The average designer's conception of these alloys as being readily weldable may not be entirely warranted, particularly with regard to the higher carbon cast materials.

This paper presents the results of an investigation into a sudden epidemic of weld cracks encountered in a Canadian magnesium plant. The methods used were statistical examination of data, metallographic examination of cracked welds and temperature measurements of the retort in service. It was determined that the cracking of welds was due to: (1) Higher than usual rigidity of retorts at the service temperature, resulting from increased carbon content; (2) location of welds within a carbide precipitation temperature zone; and (3) loads on the retorts causing plastic strain and deformation of the weld metal.

Introduction

A Canadian company, producing magnesium by the Pidgeon process, uses 35% Ni–15% Cr (H.T. alloy) retorts, heated externally in a Globar furnace to the operating temperature of 1170° C. (2138° F.). The retorts are cast in three sections—cap, barrel and condenser—and assembled by welding with commercial 35/15 electrodes. In the past the retorts exhibited service lives in the order of 300 days and generally failed by wall corrosion.

Suddenly, service life dropped to approximately 45 days and all failures were caused by cracks in the bottom area of the circumferential weld joining the condenser to the barrel. All cracks were at approximately the center of the weld and were circumferential. All weld-fractured surfaces showed a woody type of fracture; and a careful examination revealed some fine cracks in the welds and adjacent to the welds, all circumferential in direction.

The sharp reduction in service life constituted a serious problem and an investigation was launched immediately to determine the cause of failure.

Statistical Examination of Data

The magnesium production process had, prior to this outbreak, been the subject of other statistical surveys to determine optimum operating conditions and retort composition. When any such process which has previously operated smoothly and efficiently suddenly encounters serious difficulty it is immediately known that the process has been changed or a new factor has been introduced. In brief, such a sudden rash of trouble is due to an assignable cause and cannot be due to chance. This being the case, it is natural to attempt to determine whether any particular furnace, or bank of retorts within a furnace, is a source of a higher percentage of failures than other similar equipment. The possibility always exists of furnace foundations sagging and/or retort support shifting to throw new loads on the retorts. Providentially, complete records were available of all retorts and statistical examination of these data revealed that there was no significant differences in percentage failures between various furnaces or banks within furnaces. This result tended to focus attention on the retorts alone.

On further investigation it was found that the carbon content of the retorts had been increased from 0.25% maximum to 0.40% maximum in an effort to prolong service life by increasing the creep resistance at the operating temperature. It was just after the introduction of these higher carbon content retorts that the weld cracking difficulties were encountered. A statistical analysis of the data on retorts with short service life showed that there was an unquestionable correlation between carbon content and service life. Figure 1 shows a graph of service life versus carbon content. It can be shown mathematically[1] that such a distribution can be due to chance only in two out of 100 such samples; that is, it may be considered definitely proved that high-carbon content (in excess of 0.27%), or some property of the metal associated with it, was having an adverse effect on service life under the conditions of operation to which the retorts in this sample were subjected.

Metallurgical Examination

Having determined that carbon content of the retorts was a factor in shortened service life, it was considered desirable to determine the mechanism of failure. If some change of operating conditions would eliminate failures it would then be possible to secure the advantage of higher creep resistance of the higher carbon retorts. Such a change would be warranted provided it did not introduce further difficulties.

Chemical analyses were made of a number of retorts and a standard A.W.S. analysis pad prepared with the electrodes used. The following table shows analyses typical of those obtained:

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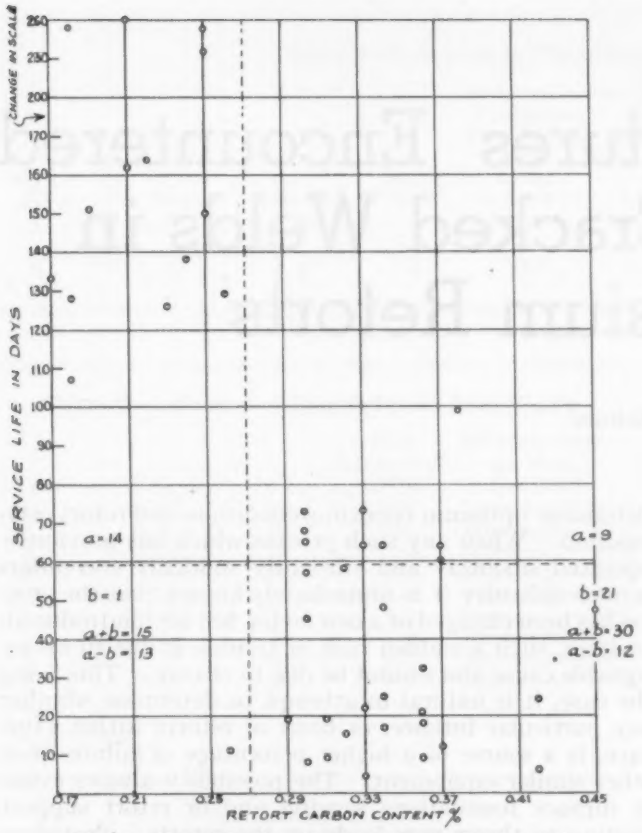

Fig. 1—Retort Carbon Content Versus Service Life

	C, %	Mn, %	Si, %	Cr, %	Ni, %	Mo, %
Retort	0.41	0.48	0.82	16.08	37.56	0.15
Weld metal	0.04	1.57	0.65	13.67	35.50	Trace

It is noteworthy that some carbon analyses ran as high as 0.45%. This is not unusual in aiming for a 0.40% maximum, but it does tend to make worse an already critical situation.

A typical cross section of a retort, including the condenser-to-barrel weld and its cracks, is shown in Fig. 2. The woody fracture characteristic of all cracked welds is shown in Fig. 3. A macrophotograph of a weld cross section with numerous cracks is shown in Fig. 4. A microscopic examination of the barrel and condenser material adjacent to the cracked areas of the weld revealed

Fig. 2—Typical Cross Section of Retort Including Condenser-to-Barrel Weld. × 1/3. Bottom View. Note Circumferential Weld Cracks

Fig. 3—Typical Woody Fracture of All Cracked Welds. × 3/4. Note Unfused Root

a typical austenitic matrix, massive chromium carbides in the grain boundaries and fine secondary carbides in the grains (Fig. 5). A similar examination of welds showed two types of secondary carbides. In areas where welds had not cracked, there were some fine nodular carbides (Fig. 6), and in cracked welds a coarser carbide in the grain boundaries and needle like carbides in the grains. The latter carbides exhibited an unusual 90° orientation one to another (Fig. 7).

Since all the heating of the retorts is from below, it is known that the bottoms are at a slightly higher temperature than the tops of the retorts. This would account for the coarser grain boundary carbides and generally larger carbides within the grains. It was theorized that the unusual orientation of the carbides within the grains might be due to precipitation along slip planes due to plastic strain or deformation of the metal. To assess the accuracy of this theory, severely deformed weld metal and an unstrained sample were heated together for 18 days at a temperature of 1400° F. Carbide precipitation is rapid at this temperature and for this reason this temperature was selected to reduce the reheating time to a minimum. After this treatment both were sub-

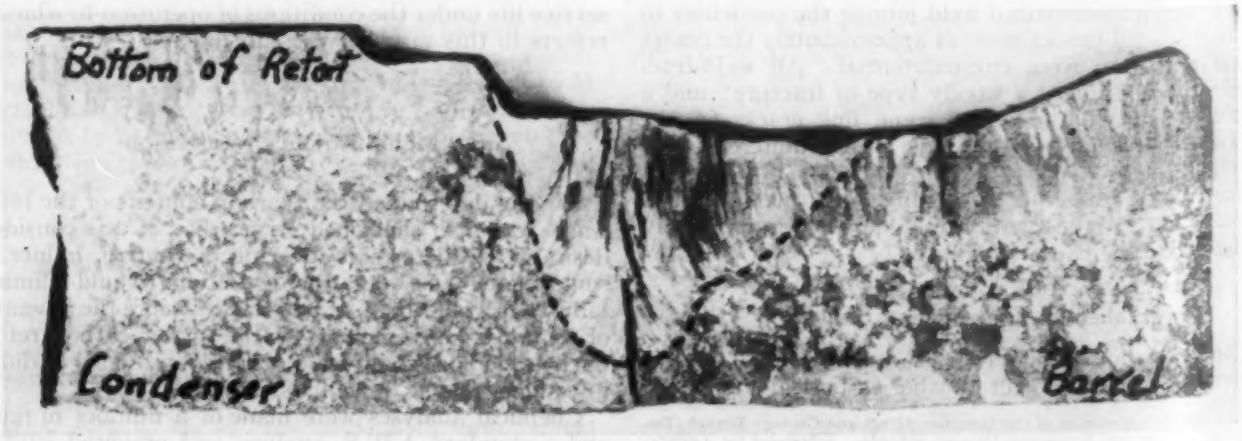

Fig. 4—Macrophotograph of Typical Cracked Weld. × 1.25. Note Profusion of Weld Cracks, Unfused Root and Crack in Barrel Material at Right

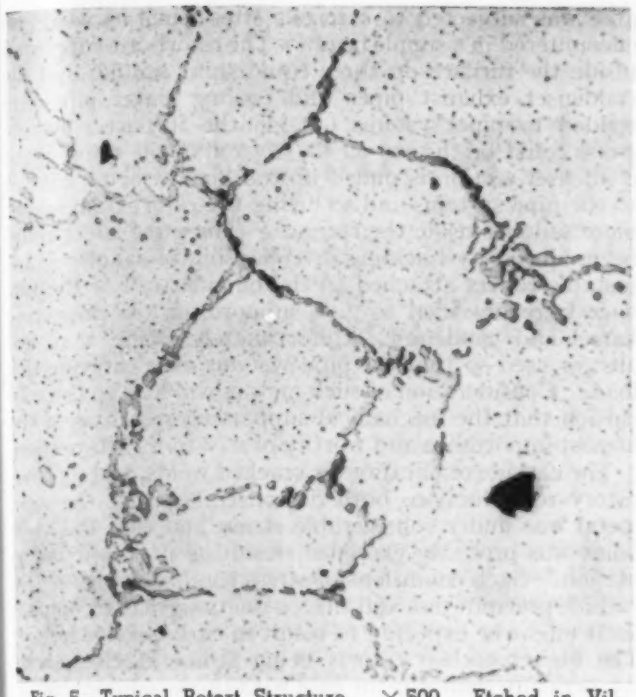

Fig. 5—Typical Retort Structure. × 500. Etched in Vilella's Reagent. Massive Grain Boundary Carbides and Fine Secondary Carbides in Grains—Austenite Matrix. Black Spots Are Casting Porosity

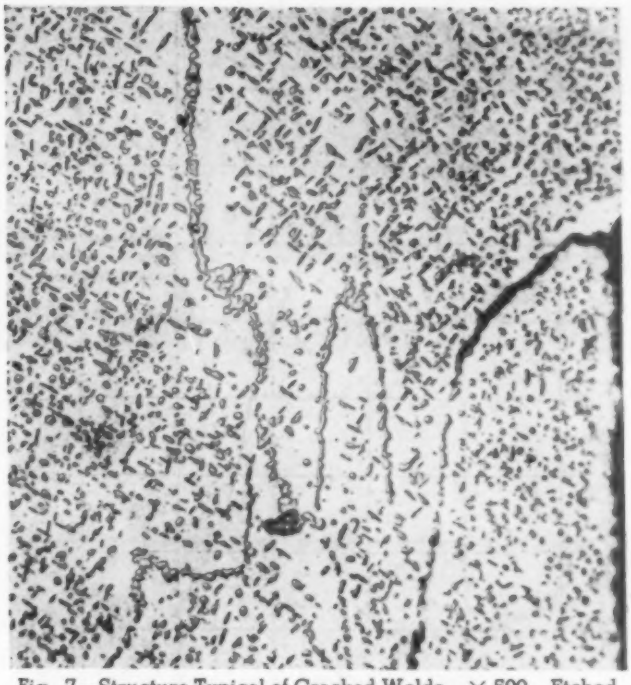

Fig. 7—Structure Typical of Cracked Welds. × 500. Etched in Vilella's Reagent. Needlelike Carbides with 90° Orientation in Grains and Coarser Carbides in Grain Boundaries. Fractures Are Following Grain Boundaries

jected to a metallographic examination. It was found that the unstrained sample showed fine nodular carbides with no preferred orientation. On the other hand, the severely deformed material exhibited the 90° carbide orientation noted in the cracked welds (Fig. 8). It should be emphasized that no such carbide orientation was detected in the retort or condenser materials.

Service Temperature Measurements

It was decided to measure the temperature over the length of the retort within which a weld might fall, since the metallographic examination of welds had revealed a higher-than-normal amount of carbide precipitation. Condenser sections are used and re-used almost indefinitely since they are not exposed to very high temperatures. The machining operation of preparing weld joints for attaching new barrels eventually necessitates the use of a condenser extension section which is usually made from scrapped barrels. Therefore the weld may shift over a considerable length of the assembly from the condenser proper toward the hot zone of the furnace. Ordinarily the end of the barrel projects through the furnace wall and from there to the end of the condenser the metal is insulated to prevent condensaton of the vaporized magnesium anywhere except at the condenser.

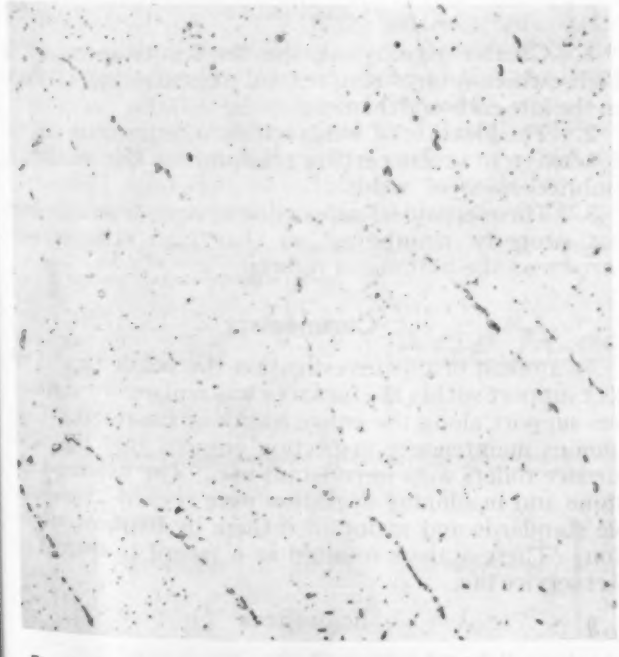

Fig. 6—Structure Typical of Uncracked Welds. × 500. Etched in Vilella's Reagent. Fine Carbides in Grains and Grain Boundaries—Austenite Matrix

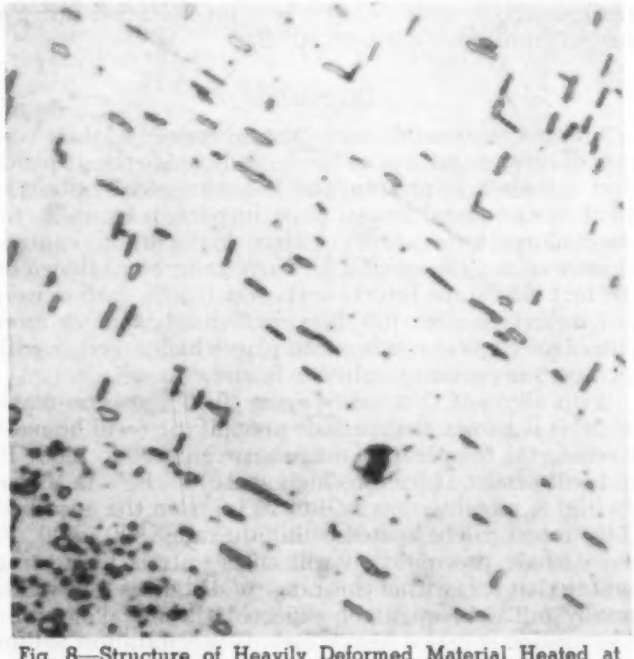

Fig. 8—Structure of Heavily Deformed Material Heated at 1400° F. for 18 days. × 1000. Etched in Vilella's Reagent. Some Agglomeration of Secondary Carbides and Needlelike Carbides with 90° Orientation

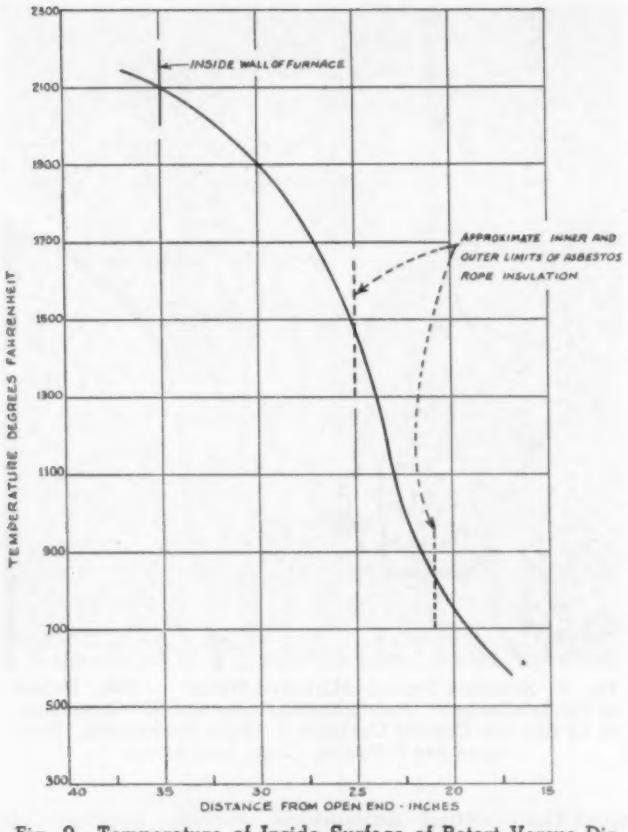

Fig. 9—Temperature of Inside Surface of Retort Versus Distance from Open End of Retort

Five holes were drilled at the bottom of the retort to within $^1/_4$ to $^1/_8$ in. of the inner surface at equal spacings from 17 to 37 in. from the open (condenser) end of the retort. Thermocouples were placed at the bottom of the holes, and ceramic cement was packed around the top of the holes. The thermocouples were then connected to a recorder. The retort was then put into service and temperature measurements made when equilibrium had been attained. Figure 9 shows the graph of position vs. temperature over the range selected. It will be noted that at distances from 20.6 to 26 in. from the open end the material is within the carbide precipitation range of temperatures from 800 to 1600° F.

Discussion

The unquestionable correlation between carbon content of retorts and service life initially led to the suspicion that carbide precipitation and the consequent embrittlement of the metal was at least in part, responsible for the failures encountered. That high-carbon content alone was not responsible for early failure was shown by the fact that some retorts with over 0.50% carbon were still in service after 100 days. Obviously, one or more other factors were coming into play which together with high-carbon content resulted in failure.

With alloys of this composition (0.40% carbon maximum) it is known that carbide precipitation will be most severe in the temperature range between 1200 to 1600° F. and will persist at least as high as 2100 ° F. As shown by Fig. 8, metal within 20.6 to 26 in. from the open end of the retort will be heated within the range 800–1600° F. and carbide precipitation will ensue. It is interesting to note that it is within this range of distances that welds usually fall. As might be expected the metallographic examination revealed heavy carbide precipitation within the cracked welds.

The most frequent appearance of cracks at the bottoms of the barrel-to-condenser welds indicated that this area was subjected to a tensile stress such as would be encountered in a simple beam. The retorts are supported inside the furnace on three equidistant saddles and the condenser exhaust pipes and cooling water pipes are welded to pipe systems outside the furnace. Tensile stress could be thrown on the bottom of the retort if the condenser section is pulled up too high prior to welding to the pipe systems and so lifting the retort from one or more saddles inside the furnace. The same effect could be produced by buckling or collapsing of saddles. Adjustable rollers attached to the outside wall of the furnace were provided to give support for the projecting barrel and condenser. Unfortunately, these were not always used so that the pipe systems were carrying this load. Consideration of such factors will lead to the conclusion that the mechanical supporting system is of the utmost importance and worthy of day-to-day inspection.

The carbide orientation in cracked welds, and its laboratory reproduction, both demonstrated that the weld metal was under considerable strain and that the yield point was probably exceeded, resulting in plastic deformation. Such conditions of stress combined with severe carbide precipitation and the contraction[2] that accompanies it might be expected to result in early service failure. The higher carbon retorts being stiffer at the service temperature than was the case with those of lower carbon content, there is a tendency to prevent uniform distribution of stress and allow its concentration in the low-carbon weld metal. Where such conditions exist and the welding technique is not the best possible, weld cracking difficulties might be expected.

Unfortunately evidences of poor welding techniques were detected, such as unfused root shown in Figs. 3 and 4. However, since all weld cracks observed apparently developed at the bottom of the retorts where maximum tension stresses would be expected, it is reasonable to assume that unfused roots were not a contributory factor. The nonuniform change of section as a result of the weld-joint machining operation, as shown in Fig. 4, is poor shop practice and further permits stress concentration in welds. This latter factor could well contribute to weld failures but is believed to be of second order importance compared with those reported above.

Conclusions

1. Greater rigidity at the service temperature of high-carbon retorts resulted in concentration of stress in the low-carbon weld metal.
2. The location of welds within a temperature range conducive to severe carbide precipitation has resulted in embrittlement of welds.
3. The mechanical supporting system of retorts were not properly maintained so that high stresses were thrown on the bottoms of retorts.

Commentary

As a result of this investigation the saddle type of retort support within the furnaces was replaced by continuous support along the entire length of the retort. Continuous maintenance inspection ensured that the outer furnace rollers were in constant use. The welding technique and machining operation were revised to acceptable standards and maintained there by frequent inspection. These actions resulted in a return to normal retort service life.

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Directional Welding to Minimize or Eliminate Distortion in Weldments and Control Residual Stresses*

By Joseph Holt†

IN WELDING, to keep distortion and stresses to a minimum, to balance the stresses and place them so they will oppose whatever load the finished weldment is to carry, it is necessary that we fully understand the basic principles of heat application and the results of the physical actions of the heated and adjacent metal.

If we take two pieces of metal and tack them together edge to edge for welding, as shown in Fig. 1, then weld them from edge *A* to edge *B*, we will get a change in alignment.

As the weld progresses from *A* toward *B*, heat is conducted into the adjacent metal causing it to expand. This expanding metal takes the course of least resistance and "upsets" or, due to the confinement, expands in thickness in the heat-affected area and weld zone because it is held from expanding transversely to the weld by the tacks. Also as the weld metal solidifies behind the arc and cools somewhat, it contracts and assists in causing the upsetting action at the point of welding.

On cooling, upset metal does not restretch unless forced to do so.

This metal upsets most at the highest temperature when most plastic and pulls most to distort the member at the lowest temperature when it is least plastic. Thus the metal is distorted as shown by the dotted lines in Fig. 1.

The shaded areas represent the heat-affected metal and the arrows show the direction of movement of the specimen. The course of least resistance is always taken by the metal, whether being heated or cooled.

Had this specimen been held rigid during the cooling process, the hot metal in the weld area would have stretched somewhat to satisfy the contraction. This stretching would continue until the elasticity of the metal itself would satisfy the final contraction, leaving the weld zone at or near yield-point tension.

* Scheduled for Twenty-Eighth Annual Meeting of A.W.S., Chicago, Ill., week of October 19, 1947.

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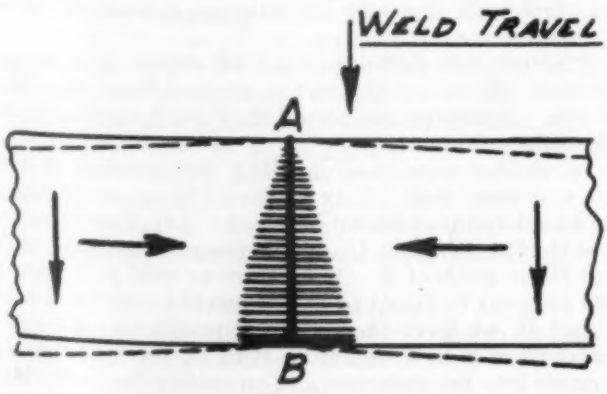

Fig. 1

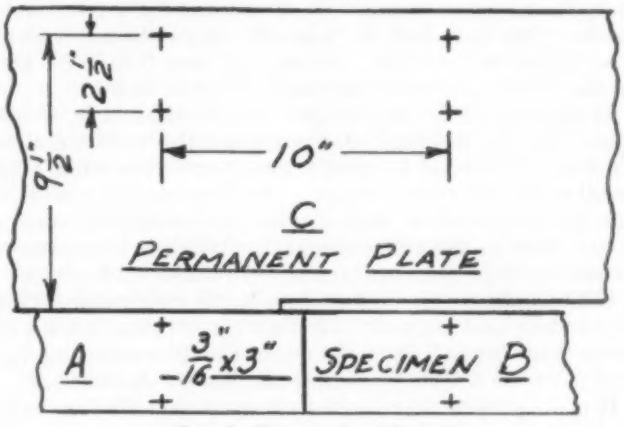

Fig. 2—Experimental Layout

The movement of the free ends in the welded specimen is always in the same direction as the weld travel, longitudinally with the weld, and always in toward the weld in transverse with it, unless some great outside force exists or is added. This is fully proven by tests made at the University of Washington as well as by years of experience in the welding field. Figure 2 shows briefly the "setup" used in the tests made at the University of Washington.

The permanent plate *C* was rigid enough to resist any movement unless its own temperature was changed. The test pieces were of mild steel 3 in. wide by $^{3}/_{16}$ in. thick, and were over 5 in. long. They were beveled 30° each and no root opening. Speed of travel of the arc was 5 in. per minute. The rod was $^{5}/_{32}$ with 160 amp. on a d.-c. machine.

The four stations on plate *C* were carefully located and drilled. It was from these points that the measurements were taken with a Whittemore strain gage for the side movement of the specimen. The movement toward the weld was measured with the same gage.

All points were carefully located and measurements taken before welding and after the specimen was fully cooled in place in atmospheric conditions. When the specimen was well tacked at both edges and the weld traveled continuously all the way across, there was an edgewise movement of approximately 0.02 in. in ten inches of length and 0.011 in. movement toward the weld one-half inch in from the starting edge. One-half inch in from the finish edge there was a movement toward the weld of 0.021 in. (see Fig. 2). *A* and *B* represent the specimen.

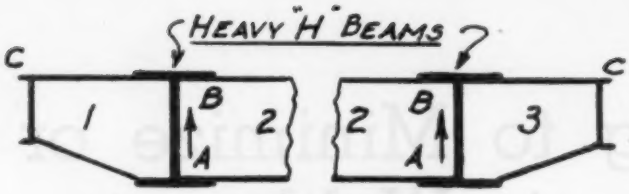

Fig. 3—Trailer Cross Section

If, however, the welds were made from the center of the specimen to the edges with the tacks the same as before, there was a movement edgewise of only 0.004 in. toward the last weld made, a movement transversely with the weld toward it of 0.0146 in. one-half inch in from the starting edge and 0.0198 in. toward the weld one-half inch in from the finish edge or side.

When the sequence was changed and the direction of weld travel was from the edges to the center of the specimen, the movement was 0.01 in. toward the second weld made. One-half inch in from the edges the movement toward the weld on the starting side was 0.0129 in. and on the finish or second weld side was 0.0185 in.

If the weld traveled toward a tack, that tack, if not heated by the welding, always caused the weld metal to stretch as it cooled to satisfy the contraction while that metal was in the plastic range. A differential in temperature of about 200° F. with proper conditions will cause a plastic flow in the affected metal. Welding heat always creates those proper conditions over considerable areas.

When a plastic flow takes place in the weld zone during the cooling and partially satisfies the stresses set up in the cooling process, it is clear that the forces causing distortion in the finished product are greatly diminished.

It is only when we consider carefully just what is happening as to expansion and contraction in the metal itself during the heat cycle of welding that we can visualize the conditions to be overcome to minimize or eliminate distortion. The course of least resistance is always followed by the metal. We must control that course of least resistance if we are to control the weldments distortion that is not generally done in the welding world today.

It is only by the direction of weld travel with regard to tacks and other forms of rigidity that we can control the course of least resistance and force the cooling metal to respond to our wishes and thus place the stresses where they will be an asset to the finished weldment.

Note Fig. 3. It is the cross section of a heavy trailer. The two heavy wide-flanged beams formed the backbone of the trailer. The formed channels, Nos. 1, 2 and 3, were welded to the beams and the channels *C* and *C*

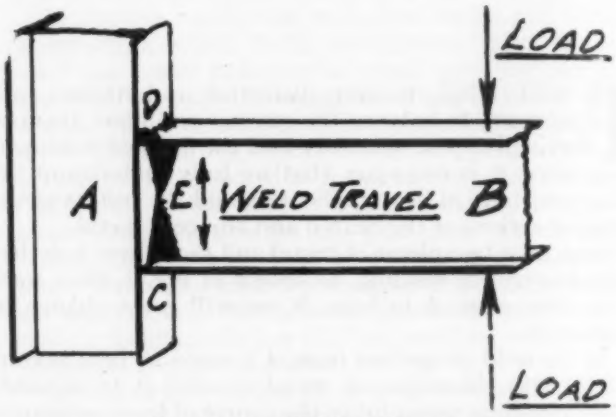

Fig. 4—Poor Welding Sequence

formed the sides. The welds between the wide-flanged beams and the formed channels traveled from *A* to *B* in the making and when the trailer was loaded to one-third its designed capacity it sagged and took a permanent set of 4 1/2 in. See Fig. 3 (*A*).

No welds were made on the flanges of the beams but they were metal so situated and rigid enough to force the weld metal to stretch on cooling to satisfy the contraction so that at points *B* the webs of the two beams were under yield-point tension. When the load was added a plastic flow occurred in the longitudinal members due to the combined effect of the residual tension and the load. This is just an example of load plus tension.

The stress areas in the webs were reversed by the proper use of the oxyacetylene torch so that the tension areas were at *A*. When 150% of the rated load was added to prove to the purchaser that the trailer would now stand up, it sagged only one-half inch and when the load was removed it came back to the proper alignment. See Fig. 3 (*B*). The stresses were opposed to the load. Had the direction of weld travel been correct when the trailer was first built it would not have sagged and taken the permanent set.

Practice has shown beyond all doubt that stresses properly placed are an asset to any weldment regardless of size. If improperly placed they are dangerous to the life of the weldment.

In all structural steel welding the direction of weld travel is very vital. Take a heavy I-beam and to it tack another I-beam as shown in Fig. 4. Let *A* and *B* represent the two I-beams, *C* and *D* represent the flanges of *B*, and *E* the webb of *B*. If we start to weld at *E*'s center and progress to *C* and to *D*, then weld across the flanges *C* and *D*, we have the following results: As the welds travel from *E* to *C* and from *E* to *D*, the heated metal expands into the weld area and on cooling the contraction puts the flanges *C* and *D* under compression. When we

Fig. 3(*A*)

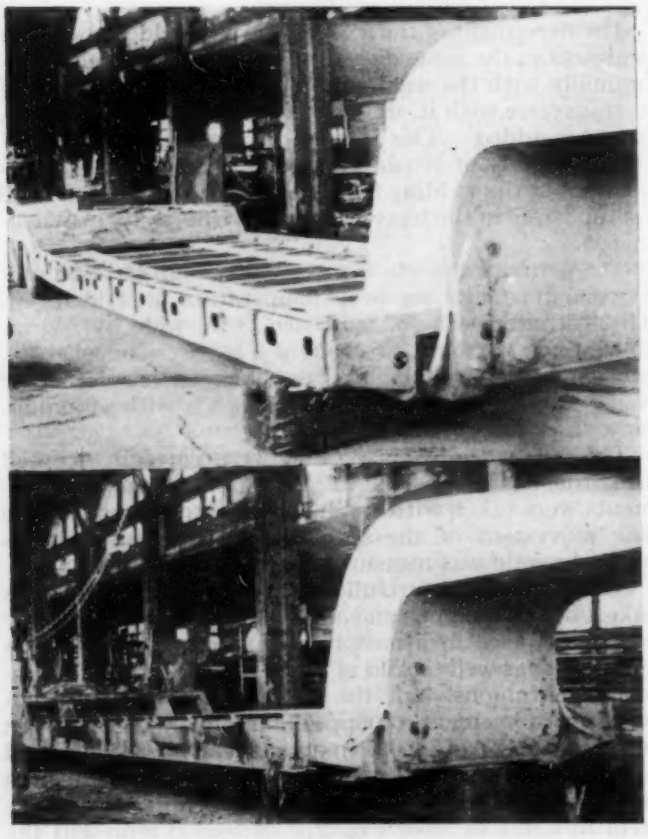

Fig. 3 (*B*)

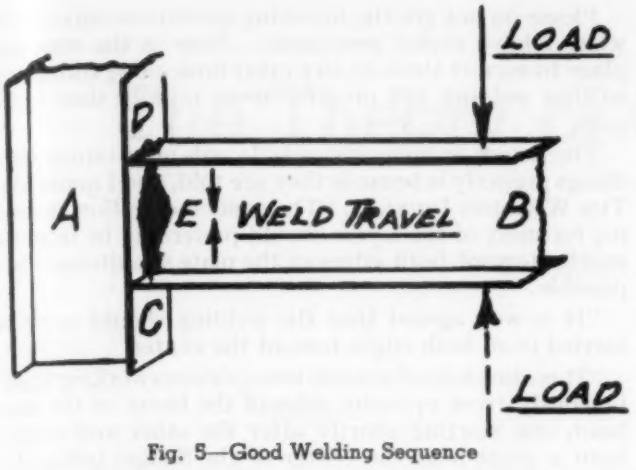

Fig. 5—Good Welding Sequence

weld C and D, this compression, together with the heat-expanded metal of the flanges, passes into the weld area in an upsetting action. If in welding C and D we weld as is usually recommended and travel from the center of the flanges to the edges, we again have the same effect and the edges of C and D come under tension on cooling. The point E is under a compression stress. No matter in what direction we load the member B, we have the stresses all working with the load to cause failure in the joint. This joint is not a safe one regardless of how good the steel, welding rod and welder are. "Why?" you may ask. Because fatigue failures occur in tension areas.

But that is not all. We have another point to consider —edge effect. The tension is on an edge at all points. That is *dynamite*. Try to tear a piece of paper, metal shim stock, canvas, or anything, by pulling on the edge. Now try to tear it by pulling through the center. Apply tension on the edge and it tears quite easily because you have edge effect. This applies to weldments of all sizes.

Now let us weld another I-beam to I-beam A correctly so as to get maximum load-carrying capacity. Weld from the edges of C and D to their centers, then from C and D to the center of the webb, or E. Here the same action takes place as to upsetting of the metal, only that because of the direction of weld travel we have the high-tension area on the final cooling located at E and the edges all under compression.

Load this member in any direction and you have to overcome a residual compression stress at the edges before any tension occurs to cause edge effect. This is worth considerable thought. All stresses in normal tension areas are opposing the load and there is no edge effect. See Fig. 5.

If you have edge effect and tension combined you can expect nothing but failure in any weldment.

It is needless for me to tell you of the advantages of the step-back or wandering sequence but have you fully studied just what happens in such sequences? They hold the key to one of the greatest forces at hand to minimize the dreaded distortion. Not the distribution of welding heat as we think of it, but the fact that the distribution of the heat leaves metal so situated and at such a temperature as to be rigid enough to force the cooling metal of the following back-step to stretch to satisfy its contraction. This plastic flow in the cooling weld does not harm it for its intended use, but rather refines its grain as tests show and field work has fully proved.

Note Fig. 6. Use this as an example.

Let X represent a plate to be welded into an assembly, all surrounding plates being completely welded, and A, B, C, D, E and F representing these plates. X must be tacked thoroughly and solidly on all sides, preferably in the centers of the seams, before the welding starts. It must be kept in mind that there should be no high-tension areas at any corner of X nor at the junction of X with any welded seam. Fatigue failures occur in tension areas, so let us place the tension areas where they will be a help and cause least trouble. Let T represent the points where you wish to have the tension located away from corners and welds.

Starting at the corners, the welds must progress toward T for about 6 in. Next, starting at the welds which join the surrounding plates and which are in contact with plate X, a weld must travel in each direction toward T for about 6 in. From then on the seams must be welded in a step-back sequence, as shown at the junction of plates A and X in Fig. 6, each rod travel to be away from T and toward the welds already made; all steps to be fully welded. Note that the general direction of weld travel as a whole is progressing toward T. The long arrows indicate the general direction of weld travel and the short arrows indicate the direction of rod tavel in back-stepping. The heavily shaded portions indicate approximately how the heat is conducted out from each step-back and the lightly shaded portion between plates B and X shows how the heat is conducted into the plate as a whole. Each causes an upsetting action in the weld and heat-affected area and on cooling causes a tension stress.

It is evident that where each step-back is started, little heat is conducted out into the plate as the weld is almost instantaneous. This point in each step-back leaves metal so situated and rigid enough to force a stretching action in the following weld as the following weld cools. This diminishes the distortion for two reasons: The metal of each step-back is forced to stretch by the previous step-back metal, and on the final cooling there is a tendency to put a tension stress across the plate at each T.

Many other examples could be given but time and space are short. However, here are a few examples of real jobs.

Figure 7 shows a small ferry under construction, built to carry cars, passengers and freight across Puget Sound. This hull was built in four sections or quarters, each quarter having three tight compartments. All the welding was done according to data given you. All distortion of any consequence was eliminated and the quarters fit together perfectly, it not being necessary to leave any metal for trim purposes. All bulkhead, bottom and deck plates were so free from distortion that no shrinking was necessary.

A tight wire stretched along one side revealed an average of only $^1/_{16}$ in. distortion between stiffeners which were two feet apart and welded continuously. In many ships I have measured as much as $2^1/_2$ in. distortion in the

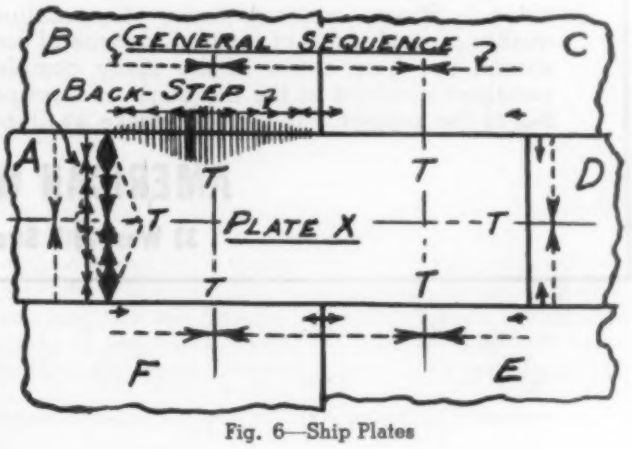

Fig. 6—Ship Plates

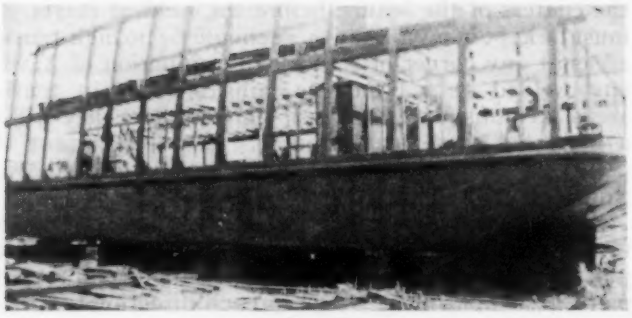

Fig. 7

same distance between stiffeners and over the entire plate in the assembly.

In one shop during the war they were months behind schedule until the distortion trouble in their weldments was whipped by directional welding. .

Main deck bedplates were very difficult to hold to alignment in welding and machining, hydraulic steerer bases were a big headache, airplane hoist beds were warped, and cargo winches seemed impossible until directional welding entered the picture. The troubles soon vanished and production was ahead of schedule in a short time.

The reason welding has made such advancement is because welding and steel are so good they do their job when given only half a chance.

Brittle Failure is so often in the headlights. Try tearing a piece of *good* steel by starting the tear at the edge and study the result. Note the grain size.

Welding toward Freedom is also a pet topic. Study and see just what freedom really is in welding.

Study also weld failures in any and all structures and over 75% of them are a direct result of edge effect plus tension.

Please do not get the following quotations mixed with what I have stated previously. Now is the time and place to correct these or any other misleading statements so that welding will progress more rapidly than in the past.

The reason so many shops and yards fail to study these things properly is because they are told, and I quote from THE WELDING JOURNAL, "The general direction of welding for most of the layers should preferably be from the middle toward both edges of the plate simultaneously if possible."

"It is well agreed that the welding should never be carried from both edges toward the center."

"It is also preferable to use two operators working simultaneously from opposite sides of the beam on the same bead, one starting shortly after the other and welding from a point near the center of the flanges toward the edges."

"The tension flange has been welded first so that the greatest tensile shrinkage stress which occurs in the last weld will be in the compression flange."

"Furthermore, it has been the object here to outline principles to be followed in setting up a foolproof procedure that will preclude all possibility of poor workmanship."

I ask you to study these quotations.

Remember, no joint can be made as strong as a welded joint and few can be made as fast. *If it is welded it stays put.*

Before closing, I wish to express my gratitude to the University of Washington and especially to Professor Gilbert S. Schaller. Also to Mr. J. R. Stitt and Mr. A. G. Bissell. It was Mr. Bissell who started me out on the problems of Expansion, Contraction and Distortion in Weldments back in the very early 1920's by outlining a research program.

FLOW AND FRACTURE OF METALS

The scientific phenomena involved in the flow and fracture of metals has engaged the attention of some of the ablest scientists in the world in recent years. The problem is particularly important in welded structures where the monolithic character of a welded assembly brings into play stresses of a three-dimensional character. Stress concentrations, temperature, quality of steel, rates of loading, degree of constraint, are only a few of the many complex variables involved in the thorough understanding of the subject. In order to make available to engineers and research workers the best existing information, two comprehensive reviews were prepared on the subject. One of them was made by Major Hollomon under the supervision of the Welding Research Council and the other by Dr. Gensamer and his associates for the U. S. Navy. The first of these is already available in book form at $1.00 per copy. The second will be available within two months, also in book form at $1.00 per copy. Orders may be placed for either or both of these books at once. Address orders to:

AMERICAN WELDING SOCIETY

33 West 39th Street, New York, 18, N. Y.

The Theory of Oxyarc Cutting*

By Hallock C. Campbell†

Abstract

Oxyarc cutting is a method of cutting, piercing and gouging any metal or alloy, using an electric arc and a stream of oxygen both conducted to the point of operation through a flux-coated tubular electrode or rod. The dimensions and composition of the steel core determine the width, depth, speed and quality of cut. The coating stabilizes the arc, seals the oxygen jet to the work, insulates the core from the work and fluxes the oxides from the cut.

The mechanism of cutting mild steel follows simple rules based on theoretical temperature distribution curves already published for idealized arc welding conditions. The rate of burn-off of the rod is proportional to the electric current and the cross-sectional area of the core, as predicted by theory. The rate of cutting is proportional to the rate at which the kindling temperature is established on the surface of the plate. The oxygen requirements are governed by the effective tip size of the tube and the speed and depth of cutting. The predictions of the theory have been helpful in establishing the optimum conditions for cutting various thicknesses of mild steel.

The mechanism of cutting oxidation-resistant metals is more complex, involving melting, diluting, fluxing and mechanical ejection. A more detailed study of this mechanism is needed before the optimum conditions for commercial cutting can be predicted.

Introduction

OXYARC cutting is a recent arrival in the field of metal fabrication. It is not recent in concept, for cutting was accomplished with hollow carbon electrodes over 20 yr. ago,[1] but it has seemed to be new since its past history is poorly documented and is mostly concerned with underwater cutting.

In the field of underwater cutting, remarkable work was accomplished by the U. S. Navy and its laboratories and shipyards during the recent war, using metallic or ceramic tubular electrodes covered with insulating, arc-stabilizing and waterproofing coatings.[2] In the field of "surface" or open-air cutting simultaneous independent development of this process was carried on secretly in Belgium during the German occupation, resulting in the first public use in Europe in January 1945.[3] Numerous articles have appeared in this country following the demonstration of the process at the National Metals Congress in November 1946.[4–9] Economical industrial methods first had to be devised to produce heavy wall tubing in small diameters and coating formulation had to be adopted to the new application.

The success of the Oxyarc method in cutting all kinds of metals, whether nonferrous or ferrous, oxidizable or stainless, high melting or low melting, is directly attributed to the characteristic structure of the cutting or reaction zone at the tip of the rod, namely, a concentrated source of intense heat directly surrounding a jet of oxygen. It is the purpose of this paper to describe the method systematically and critically, in order to deduce the underlying mechanism and to develop a theory of operation based on physical and chemical principles. This has been accomplished both qualitatively and to some extent quantitatively. The quantitative theory is imperfect in some respects, but future research should be able to correct and improve it. The theory has proved useful even in its present form in smoothing experimental data, in predicting the operating conditions needed for cuts of similar quality in untested thicknesses of plate and in interpreting the phenomena observed when cutting various nonferrous metals and from them predicting the conditions required for better cuts.

Terminology

The development of arc-oxygen‡ cutting has necessarily borrowed certain terminologies from the arc-welding process and the oxyacetylene cutting process. Most of the terms are familiar to workers in both fields. In order to itemize the major terms in preparation for latter discussion, the following survey of the process and its equipment is given.

The Oxyarc process, as its name implies, uses oxygen, which is taken from any conventional source, and an electric arc, which is supplied by a welding generator or transformer. A holder of special design is required in order to connect the oxygen and the electric current to the rod at one and the same time. In Europe, where welders prefer to use a hand shield, the holder is of simple design and the necessary oxygen valve is placed in the handle of the shield for the operator to trigger with his left hand. In this country the oxygen valve is made part of the holder. Commercially successful holders now in use are the U. S. Navy holder for underwater cutting, several modifications of it designed for open-air cutting, and a spring-loaded holder developed by the author's company. Since this external equipment is not a part of the theory of Oxyarc cutting it will not be further discussed in this paper.

The process centers around the tube or rod which conducts the oxygen and the electric current to the point of operation. The rod is consumed by the arc during the cutting process as though it were an arc-welding electrode, and is often termed an electrode; it is preferably called a tube or rod since it does not deposit weld metal when used as a cutting tool. The rod consists of a tubular metallic core covered with a mineral type coating.

The core may be of seamless tubing, but is more usually formed from strip into an open-seamed tubing. It possesses physical attributes such as dimensions (inside and outside diameters, and length), density, a specific heat, electrical and thermal conductivity, and melting point.

* Scheduled for Twenty-Eighth Annual Meeting, A.W.S., Chicago, Ill. week of Oct. 19, 1947.

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‡ Here frequently referred to by the Arcos trade mark Oxyarc.

It possesses chemical attributes related to its chemical composition, such as a kindling temperature if it is a combustible metal.

The exterior coating of the rod consists of binders, arc stabilizing ingredients and fluxing and slag-forming ingredients. The coating possesses physical attributes such as a certain thickness (usually reported in terms of the outside diameter), a capacity to insulate the core electrically from the work piece, a temperature range of plasticity, a melting point, a certain fluidity when molten and a degree of ionization within the electric arc. It possesses chemical attributes dependent on its chemical composition, and may produce a slag which is acidic or basic with ability to flux or react with various metallic oxides.

Method of Operation

The Oxyarc method of cutting, piercing and gouging uses less welding technique than any other arc or gas cutting method. It is not necessary to hold an arc in the sense that a welder maintains an arc, for the rod is operated by touch-welding methods, keeping the coating in contact with the plate metal at all times. As will be described in a later paragraph, the coating burns off at a slower rate than the rod, and thereby insulates the core from the work and automatically maintains the proper length of arc.

The operation of piercing will be described prior to the operation of cutting, since piercing so often precedes cutting in practical operations, particularly when cutting holes and openings in the interior of large plates. The start of both cutting and piercing is the same: the tip of the rod is tapped on the work at the desired location as though striking an arc for welding and the arc is "held" for a moment while the oxygen valve is being opened. In piercing, the rod is then pushed into and through the plate as fast as the hole is formed, for the piercing action begins immediately. There is a momentary shower of sparks and slag which is projected upward from the plate as the piercing begins, but this subsides as soon as the tip of the rod begins to penetrate into the plate.

In cutting, the tip of the rod is scratched or tapped on the plate to strike an arc without freezing fast to the plate, and the oxygen is released. The rod is then dragged along the surface of the plate at the speed of forward travel dictated by the progress of the cut. No arc length is consciously held, but rather the tip of the rod is held against the plate and the operator slides or feels his way along, riding on the insulating crucible of coating at the tip of the rod. The inclination of the rod and the speed of motion are adjusted to give the most efficient and highest quality cut. Template-guided cutting is very common. The insulating coating permits the operator to press the rod against the template without fear of arcing against it. For straight line cuts any straight edge (metallic or not) may be clamped along the line of operation. The cut is accomplished by holding the rod against the guide and the plate at the same time. Circular openings in partially fabricated tanks have been cut by using the inside circumference of a suitably sized pipe as the guiding template.

Gouging is performed by inclining the rod, after striking the arc and releasing the oxygen stream, until it is almost parallel to the plate surface and pointed away from the operator and along the line of the prospective gouge. The arc and oxygen bite into the plate and pile up a pool of slag and oxides beyond the tip of the rod. The rod is pushed rapidly along over the surface of the plate, in pursuit as it were of the receding pool of oxidized metal.

The speed of cut which can be achieved by an experienced operator varies with the thickness and composition of the plate, with the oxygen pressure and current and voltage, and with the dimensions of the cutting rod. A few figures are given in Table 1 for purpose of reference in the mathematical section of this paper. Some of the data for stainless and nonferrous alloys have already been published.[6] The data for mild steel are a partial presentation of a consistent study conducted by one welder, using a recording volt meter and ammeter to obtain the time and current records. They are supplemented by data taken from the Belgian publication.[3] For reference later the approximate relation between the voltage and amperage in Oxyarc cutting is shown in Fig. 1. Data from Table 1 and from additional sources are included. It will be noted that the total oxygen pressure has little effect on the arc voltage. The normal relation in arc welding is schematically shown along the lower edge of the graph.

Functions of the Core

The core conducts the electric current and the oxygen to the point of cutting. The various functions performed by the core will be discussed individually.

The burn-off rate, that is, the rate of consumption of the rod, is one of the controlling factors in the economics

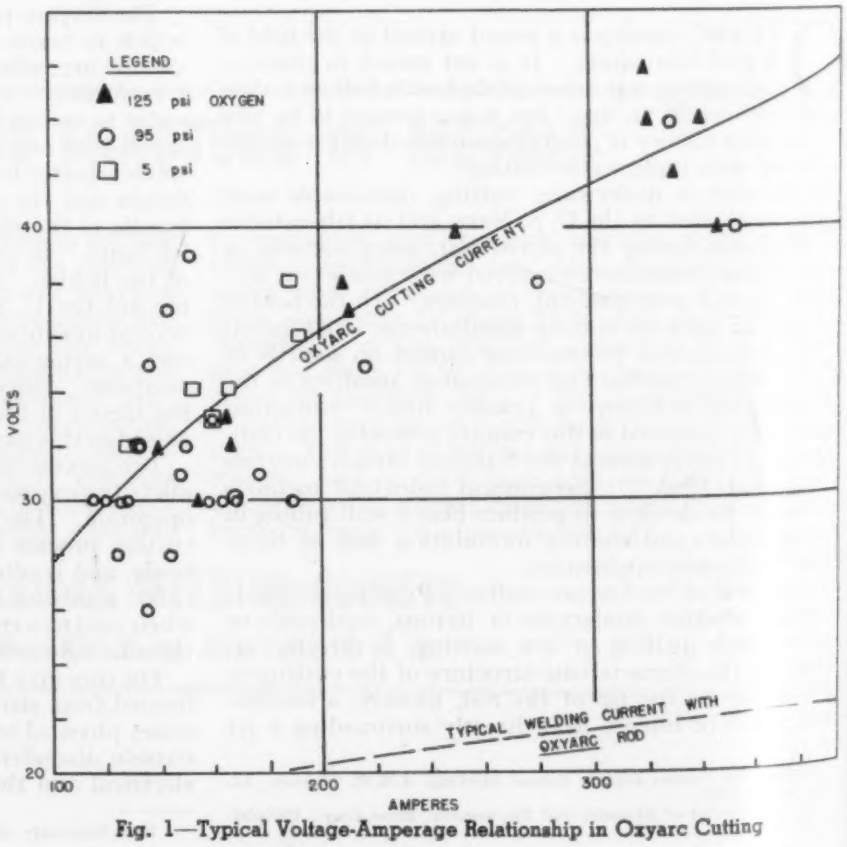


Fig. 1—Typical Voltage-Amperage Relationship in Oxyarc Cutting

of cutting, since the lowest burn-off rate consistent with the highest cutting speeds will give the most efficient cutting. The rate of consumption depends upon several variables, notably the dimensions and composition of the core, the current (but apparently not the voltage) and the oxygen flow rate. The dimensions and composition of the core determine the heat capacity, electrical resistivity, thermal conductivity and melting temperature of the rod; the melting rate is mathematically related to these factors and to the intensity of the current supplying the arc.

The effect of the oxygen flowing through the center of the rod is to cool the rod everywhere except at the tip, where oxidation occurs. The cooling effect is great enough to prevent overheating of the stub even at high currents; however, its effect on the burn-off rate is believed small. The effect of the heat generated by the combustion of the core is also believed unimportant, for the products of combustion are driven away from the rod by the oxygen stream, so that the heat liberated by this reaction is transferred to the edges and sides of the cut rather than to the end of the rod. The exact effect of oxygen on the burn-off rate is not easily demonstrated, because there is a characteristic lengthening of the arc which results when the gas stream is flowing. This changes the voltage and amperage conditions and prevents a direct comparison between burn-off rates with and without oxygen. Exploratory tests have shown that the oxygen effect is at least smaller than the other experimental variables.

Table 1

Rod O.D. x I.D.	Current: Amp.	Current: V.	Current: Kw.*	Oxygen, Psi.	Time, Sec.	Length Cut, In.	Rod Burn-off, In.	Cutting Speed, In./Min.	Burn-off Rate Cu. In./Min
				1/4-In. Mild Steel					
5/16 x 0.063 in.	145	..	4.7	70	18	12	5	40.0	0.41
5/16 x 0.063 in.	155	..	5.1	70	16	12	4.5	45.0	0.42
5/16 x 0.063 in.	276	..	11.2	125	9	12	5	80.0	0.82
5/16 x 0.063 in.	280	..	11.4	75	10	12	4.8	72.0	0.71
5/16 x 0.063 in.	280	..	11.4	75	10	12	5	72.0	0.74
				3/4-In. Mild Steel					
5/16 x 0.063 in.	120	30	3.6	95	30	12	7.3	24.0	0.36
5/16 x 0.078 in.	140	32	4.5	125	28	12	8.3	25.8	0.41
5/16 x 0.078 in.	164	33	5.4	125	23	12	8.5	31.4	0.51
5/16 x 0.063 in.	208	38	7.9	120	20	12	8	36.0	0.59
5/16 x 0.063 in.	216	..	8.0	95	20	12	8.8	36.0	0.65
5/16 x 0.063 in.	330	42	13.8	120	15	12	9.5	48.0	0.93
5/16 x 0.063 in.	346	..	15.2	120	15	12	9	48.0	0.89
				1-In. Mild Steel					
5/16 x 0.063 in.	180	..	6.3	90	30.6	12	9.3	23.5	0.45
5/16 x 0.078 in.	180	..	6.3	90	28.2	12	8.8	25.5	0.43
5/16 x 0.078 in.	275	..	11.1	90	19.2	10.5	9.5	33.0	0.69
				1 1/2-In. Mild Steel					
5/16 x 0.078 in.	120†	..	3.6	75	50.5	11.3	..	13.4	..
5 x 2 mm.	140	..	4.5	85	...	..	..	15.1	..
7 x 2 mm.	164	..	5.6	80	65	13.8	11	12.7	0.55
7 x 2 mm.	175	..	6.1	80	..	..	..	15.1	..
7 x 3 mm.	178	..	6.2	80	43	13.8	8	19.2	0.55
7 x 3 mm.	208	..	7.6	80	44	13.8	9	18.8	0.60
7 x 2.5 mm.	210	..	7.7	80	51	13.8	9	16.2	0.55
7 x 2 mm.	210	..	7.7	80	60	13.8	10	13.8	0.56
5/16 x 0.078 in.	320	..	13.6	125	17	6	12	21.0	0.98
5/16 x 0.078 in.	320	..	13.6	125	15	6	11.3	24.0	1.04
				2-In. Mild Steel					
7 x 2.0 mm.	200	..	7.2	85	...	..	..	11.8	..
7 x 2.5 mm.	200	..	7.2	80	...	..	..	17.7	0.68
				2 3/8-In. Mild Steel					
7 x 2.5 mm.	220	..	8.3	90	...	..	..	14.4	0.66
				3-In. Mild Steel					
7 x 3 mm.	240	..	9.3	110	...	..	..	11.8	..
7 x 2.5 mm.	260	..	10.3	115	...	..	..	11.1	0.67
7 x 3mm.	272	..	11.0	100	53	10	14	11 3	0.82
7 x 3 mm.	276	..	11.2	100	82	13.8	23	10.0	0.85
				4-In. Mild Steel					
7 x 3 mm.	280	..	11.4	120	...	..	..	9.1	..
				Stainless Steel and Nonferrous Metals					
				5/16 x 0.063-Oxyarc Rods					
1/4-in. Type 347	290†	..	..	80	...	..	..	9.8	1.01
1/4-in. Inconel	165	34	..	10	138	12	40	5.5	0.43
1/4-in. Monel	130	31	..	5	126	12	31	5.5	0.37
1-in. Monel	250	..	..	40	147	6.6	..	2.7	..
1/4-in. Nickel	160	33	..	4	116	12	..	6.3	..
1/4-in. Copper	275	..	..	20	15	4	8	16.0	0.79
1/4-in. Bronze	350†	..	..	40	...	..	..	10.5	0.94

* When voltage is not given, arc energy has been computed from Fig. 1.
† Alternating current.

Of lesser effect in determining the burn-off rate are the thermal insulation provided by the coating, and the energy absorbed from the arc during the fusion and vaporization of the coating. Since it has been estimated that all radiation, fusion and vaporization losses amount roughly to only 15% of the energy of the arc,[9] rather large variations in these quantities will result in but small variations in the burn-off rate.

The inside and outside diameters of the core control the speed and quality of cutting or piercing. The outside diameter has a direct effect on the speed of cutting, seemingly through its influence on the shape and size of the arc and through that on the size of the preheated area of the plate. The metal being cut must be heated to within the kindling or melting range. Large electrodes are apparently less efficient in this respect than small ones, which are able to act more nearly as "point" sources of heat. The inside diameter controls the size and velocity of the oxygen stream, the velocity varying of course with the pressure. The effect of oxygen on the quality of cut is a complicated function of both the linear velocity of the oxygen stream or jet and of the total volumetric rate of flow of the oxygen. However, the velocity seems to be less important than the total volume of oxygen. As long as sufficient velocity is imparted to the jet to carry the oxidized and molten core metal down through the full depth of plate being cut, the speed, efficiency and quality of cutting seem more affected by the volume of oxygen. There is not much experimental evidence available to support this view, except for the following illustration from a field demonstration. In cutting 1/4-in. Type 347 stainless steel with two types of Oxyarc rods, both of which had the same outside diameters but which differed in inside diameter, it was observed that equal quality of cutting was obtained at approximately 5 psi. of oxygen when using a 0.063-in. bore and at approximately 3 psi. of oxygen when using a 0.078-in. bore. The volumetric rate of oxygen flow is about the same in both cases.

In cutting mild steel, the optimum inside diameter of the rod is related to the thickness of the plate. The general principle is the one followed in oxyacetylene cutting, where larger orifices are used for the thicker plates. Because of frictional losses in the holder and because of the length of the oxygen path through the rod, the effective inside diameter of an Oxyarc rod is much smaller than its apparent diameter.

In the piercing operation either the inside diameter of the core or the outside diameter of the coating may be involved. In piercing thin plates the diameter of the hole in the plate is approximately the same as the inside diameter of the rod. In piercing thicker plates, where the rod itself is pushed into and through the plate, the diameter of the hole is somewhat larger than the outside diameter of the coating.

The chemical composition of the core controls several factors affecting the burn-off rate, and also influences the quality and speed of cutting. The effect of chemical composition on the burn-off rate is of minor importance compared to its effect on the quality of cut. Consider a stainless steel core, for example, which will have a slower burn-off rate than a mild steel core. The mild steel core adds to the arc energy the heat liberated by its own combustion plus a fluxing and diluting action that easily permits cutting nonoxidizable materials, while the stainless steel core will be able to cut the same metals only with difficulty. The difference lies in the composition of the arc-and-oxygen "flame" projecting from the tip of the rod. If the core material is stainless steel or a nonferrous alloy, the arc stream consists largely of molten metal and carries only the energy content of the arc. If the core is mild steel, then the arc stream is believed to be largely iron oxide, and the combustion of the iron to iron oxide has liberated an additional quantity of heat amounting in most instances to more energy than was generated by the arc itself. This heat is probably not generated instantly the way the arc is, and thus is able to transfer heat to the plate at a considerable distance from the tip of the rod. This function of the iron (as such) in the standard Oxyarc core is equivalent to the function of the iron powder which is injected into the oxyacetylene flame in the powder-injection method of cutting stainless steel and nonferrous metals. The iron oxide and molten iron and the additional heat of combustion which result from the melting and combustion of the core serve to dilute, flux and liquefy the oxides, scale and molten metal formed from the plate material, so that they will all be rapidly blown out of the cut by the oxygen stream. Excess oxygen is provided to insure complete combustion of the core metal so as the preclude the possibility of contamination of the plate metal by the rod.

Functions of the Coating

The coating performs a multitude of functions which will be discussed individually.

The coating seals the seam in the core, if open-seamed tubing is used. Any openings in the seam which did not become closed during the forming operation are effectively sealed by the surrounding coating.

The coating stabilizes the electric arc. This is an important function, permitting the rod to be operated with ease on either alternating or direct current and adapting it to use by unskilled technicians. The value of the coating in stabilizing the arc is clearly shown by experiments with bare tubes. Using uncoated tubes, a skillful operator can perform a certain degree of cutting, but only by working at higher currents than normal or by using a superimposed high-frequency arc. The characteristic complaint in such tests is that the arc is quite difficult to maintain even before the oxygen stream is started; the process of turning on the oxygen then almost invariably blows out the arc. The coating also concentrates the arc onto the plate, by reason of the crucible formed by the coating at the tip of the rod. This leads to efficient heat transfer and a narrow kerf. In experiments performed with uncoated tubes the arc was undesirably large and brushlike, melting a wider area of plate material than normal.

The coating seals the oxygen jet to the work, thereby increasing the speed and efficiency of cutting. This also is a result of the formation of a crucible about the arc. Because of the insulating nature of the coating the rod may then be dragged along the surface of the metal to be cut, with the coating in contact with the work at several points. This in general prevents the oxygen from escaping other than through the kerf of the cut. In the absence of a crucible the stream of oxygen fans out so that not all of the oxygen goes through the cut. This results in a poor quality cut with tapering kerf, and is accomplished only at the expense of a considerable increase in oxygen consumption and a marked decrease in speed.

The coating simplifies the operation of the rod in two other ways. The crucible at the tip maintains proper arc length automatically, by permitting a contact method of operating. This greatly reduces the training time necessary in learning to use the rod. In addition, the coating creates a smooth "heel" or cushion on which the operator slides the rod. This function contributes notably to the ease of operation of the rod.

The coating aids in fluxing oxides and molten metal from the cut. This function is of considerable importance in the cutting of metals which form refractory oxides. It is equivalent to the function of the flux which is injected into the oxyacetylene flame in the flux-injection method of cutting stainless steel.

The coating also serves to insulate the core from accidental short circuit to the work. This permits a number of related operations which are of considerable practical importance. The insulation permits the use of metallic straight edges or templates to guide the cut. It permits cutting large pipes from one side only, by cutting half around the pipe and then reaching through the slot to cut the opposite side. It permits cutting and piercing operations in confined spaces where other obstructions might short circuit the rod. Finally, it permits efficient piercing by insulating the core from the edges of the hole. In thick plates where several rods are required to complete the piercing, it permits re-establishing the arc at the bottom of the hole (rather than along the sides) when the used rod is replaced by a new one.

The outside diameter and the chemical composition of the coating influence all of the coating functions described above. The outside diameter influences the other functions through its control over the total volume of coating ingredients present around the core. The chemical composition modifies the other functions directly, through its control of the physical and chemical properties of the coating. Successful coating formulations are similar to those used on arc-welding electrodes. The arc stabilizing, slagging and fluxing components of the coating are selected and formulated to give all-position A.-C.-D.-C. operating characteristics and at the same time (through control of the melting point) to create the desired crucible at the tip of the rod.

The Theory of Operation

The mechanism by which metals are severed in Oxyarc cutting is a combination of melting and oxidizing. In mild steel the phenomenon is the same as in oxyacetylene cutting. As is well known oxygen alone will cut mild steel when the temperature of the metal reaches its kindling point, usually estimated to be 1600° F.[14] The oxidation or combustion reaction is self sustaining within the body of the object, liberating sufficient heat to maintain or exceed the kindling temperature on all sides of the cut. At the upper surface, however, the time lag in the reaction (which tends to liberate the heat of reaction below the point of oxidation), the radiation losses into the air and the cooling effect of the oxygen stream all combine to lower the temperature below the kindling point, and the cut will be lost unless the surface is continuously preheated. In the Oxyarc process the necessary preheat is provided by the electric arc at the very point of impingement of the oxygen on the surface of the steel.

For oxidation-resistant metals the cutting mechanism seems to be more of a melting action, of various degrees of complexity depending on the nature of the metal.

The mechanism of cutting either of these classes of metals requires the achieving of a certain minimum temperature within the zone of operation. In mild steel the zone to be preheated is a small area on the surface of the metal; in oxidation-resistant alloys the zone of operation is the whole leading edge of the cut. Both cases fundamentally are problems in heat transfer. It is therefore believed that both problems should be amenable to treatment from a purely theoretical viewpoint. This has been attempted in the following sections of this paper, with varying success depending on the degree of complication of the problems studied.

The Rate of Burn-off of the Rod

In arc welding, the rate at which an electrode burns off has been shown by Rosenthal [10, 12] to be directly proportional to the welding current. This is in agreement with the theory of moving heat sources which Rosenthal has used to study the temperature distribution within an electrode. The theory describes the burn-off process in a semi-infinite solid electrode, and the "settled conditions" which become established during an infinitely long welding run. The temperature distribution about such an arc is stationary when referred to a system of coordinates moving with the arc. It will be shown that the same theory may be applied quite successfully to the burning-off of an Oxyarc rod.

The cross-sectional area of the Oxyarc rod is small relative to its length, permitting it to be considered a one-dimensional rod. During cutting exactly as in welding, a quasi-stationary temperature gradient becomes established within the rod as a result of the conduction of heat from the hot arc to the cooler portions of the rod. Since this gradient is very steep, the equations developed for an infinite rod are found to be fairly accurate when applied to a finite rod. The conditions in cutting differ from the conditions in welding largely with respect to the "melting point" of the rod. The Oxyarc rod needs only to reach its kindling temperature of 1600° F. instead of its melting point. It therefore has a faster burn-off rate.

It has been shown by Rosenthal [12] that the rate of fusion V of a solid rod is given by the expression

$$V = \frac{fi}{(T_1 - T_0)\, C\rho} = f_0 i \qquad (1)$$

in which the symbols have the meanings and units listed in Table 2. The approximate values of these and other symbols used in the succeeding calculations are also given. The values listed for C and ρ are valid only at room temperature whereas average values over the temperature range in question are required. For relative tests comparing different rods the error will be small.

The illustrative data available to the author cover only stainless electrodes and Oxyarc rods. All of the tests were made under identical experimental conditions. The burn-off coefficient f_0 for commercial Type 308 electrodes was approximately 1.7×10^{-3} cu. in. per ampere per minute, as shown in Fig. 2. This value is 10% higher than the maximum listed by Rosenthal as being common for mild steel electrodes; the discrepancy is probably due to the nature of the coatings used on the two types of electrodes. The average burn-off coefficient for Oxyarc rods under a great variety of oxygen pressures and operating currents was 3.0×10^{-3} cu. in. per ampere per minute, as shown in the same Fig. 2. The observed rate was thus 1.77 times faster for the Oxyarc rods. Using the values of T_1, T_0, C and ρ listed in Table 2, with T_1 for welding taken as the melting temperature and T_1 for cutting as the kindling temperature, it is found that Equation 1 would predict a burn-off rate 1.84 times faster for Oxyarc rods than for Type 308 electrodes. This would seem to be a fairly encouraging agreement at the present stage of development of the theory.

The proportionality between the burn-off rate and the current intensity is clearly demonstrated in Fig. 2. Included in that graph are data obtained in Europe[3] with rods of two different outside diameters and four different bore diameters, and data from this country with two bore diameters. Not shown in this figure are a considerable number of data points obtained by the U. S. Navy in underwater tests of a $^5/_{16}$-in. underwater cutting rod; the scatter of these points is rather bad because of inaccuracies in timing the diver, but their statistical average agrees very well with the line drawn in Fig. 2 for open-air cutting. Attempts to plot the burn-off rate against the arc energy in watts show a pronounced curvature; the burn-off rate thus seems to be unaffected by the voltage.

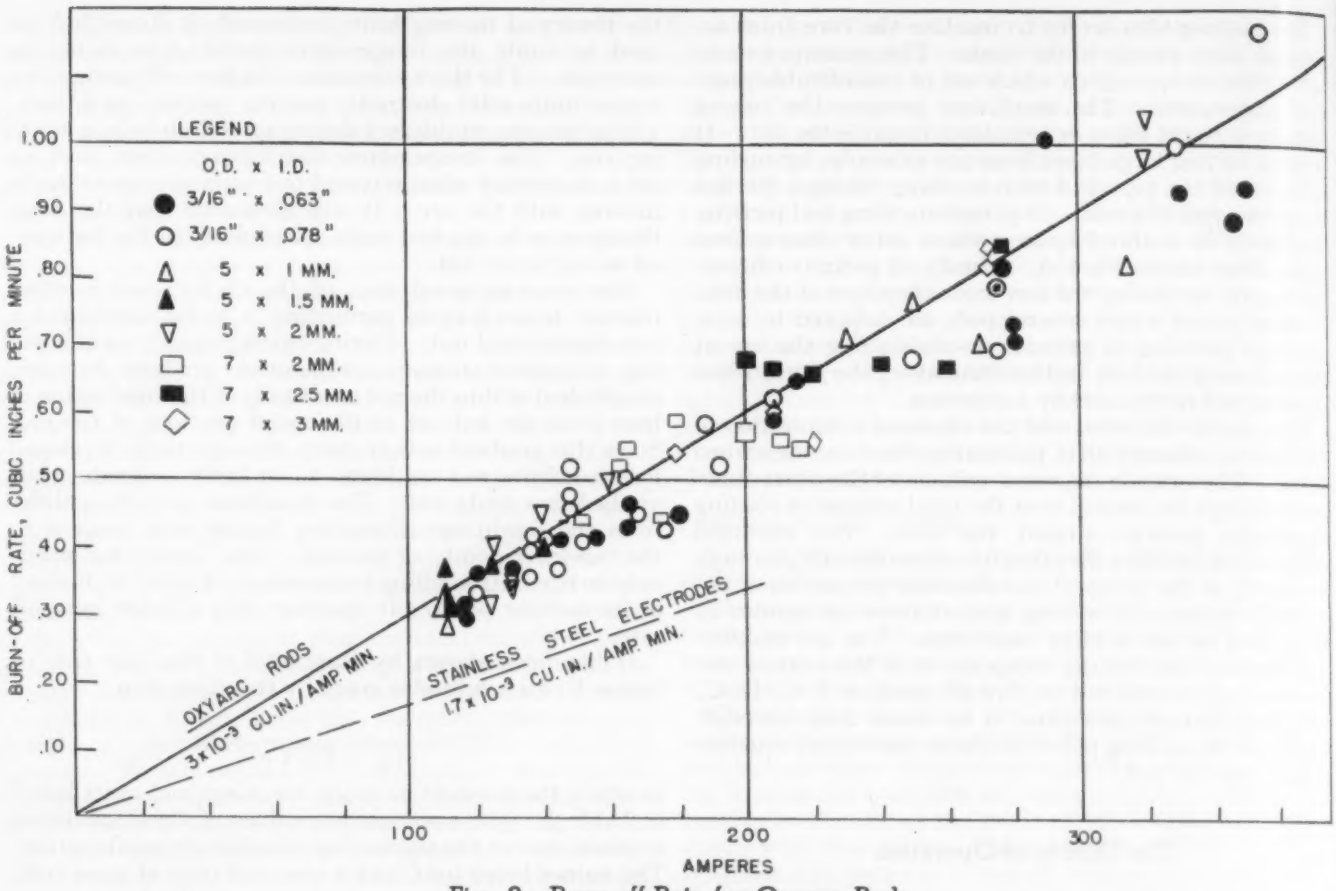


Fig. 2—Burn-off Rate for Oxyarc Rods

The effect of piercing and gouging on the rate of burn-off should be mentioned in passing. The few figures available indicate a much higher burn-off rate in piercing than in normal cutting, roughly double the rate for cutting. This would seemingly be explained by the greater build-up of heat about the tip of the rod as it is pushed into the molten puddle of metal and slag, resulting in a greater amount of heat being transferred from the arc to the rod.

Several important rules or relationships can immediately be deduced from this theoretical picture of the burn-off rate. First, there is the obvious fact that the rate of consumption of the rod does depend on the operating current. This is not generally appreciated, as is evidenced by the oft-quoted rule of thumb that the burn-off rate is "a rod a minute." Ronay and Jensen quote the same rule for underwater cutting, namely, that "the service life... averages one minute".[2] For the $^5/_{16}$-in. underwater rod this rule is correct at 275 amp., which happens to be the middle of the recommended underwater operating range. For the $^3/_{16}$-in. rods used for open-air cutting the rule is correct at 135 amp., which is about the lowest current used in practice. At 270 amp., which is near the top of the recommended range, the burn-off rate is two rods per minute.

This rather obvious point is worth stressing, since it is one of the controlling factors in determining the optimum cutting conditions. It will be shown later that the speed of cutting also increases with increasing current (or more accurately with increasing wattage), but it does so somewhat less rapidly than the burn-off rate does. Since higher cutting speeds will save both time and labor, the use of higher and higher currents would seem to be desirable. The upper limit is determined by the skill of the operator in handling the arc at high currents. Unless his speed of cutting approaches the maximum permitted by the current setting, the inexorable consumption of the rod by the arc may more than offset the expected savings in cost. The highest currents may demand greater cutting skill than the operator can summon, and may in fact only prove efficient for the most experienced operators. Lower currents which are more suited to the ability of the operator will usually save more in terms of rod consumption per inch of cut than will be lost in man-hours added because of the slower speed.

A second relationship involving Equation 1 has been discussed by Rosenthal in his article on welding.[10] This problem concerns the estimation of the fraction of the total heat of the arc which is available to heat the plate. This quantity will be needed later in developing the formulas for the speed of cutting. It is obtained by subtracting from the total heat of the arc the heat absorbed by the rod and the coating, and the heat lost by radiation.

The heat absorbed by the rod is shown by Rosenthal[12] to be proportional to the product of the burn-off rate V and the temperature difference $T_1 - T_0$. Since by Equation 1 the burn-off rate is inversely proportional to the temperature difference $T_1 - T_0$, the heat absorbed by the rod is independent of that temperature. This relationship is easily rationalized. Consider a mild steel Oxyarc rod being operated first without oxygen and then with it. During the welding operation the rod must be heated to the melting point (2768° F.), which absorbs a large total quantity of heat and results in slow burn-off. During the cutting operation the rod is not melted but burned (at 1600° F.), which requires less energy absorption per unit of length but consumes the rod proportionately faster. These two effects exactly compensate for each other, so that the energy absorption per unit of time remains constant.

For solid mild steel electrodes Rosenthal shows that

the fraction of the arc energy which is absorbed by the core is "less than 20%." The same figure, namely 20%, will be used for Oxyarc rods. The quantity of heat absorbed by the coating, lost by radiation or otherwise not transmitted to the plate, will be assumed to be 15%, again following Rosenthal. The fraction of the arc energy which is transferred to the plate is therefore assumed to be about 65%. At a power factor of 1, an arc drawing I amp. at E v. (1 w. = 0.057 Btu. per minute) will deliver Q_{arc} Btu.'s of heat per minute to the surface of the plate, to be computed as follows:

$$Q_{arc} = 0.65 \times 0.057EI = 0.037EI \qquad (2)$$

An arc drawing 185 amp. at 35 v. will have an effective heating capacity of 238 Btu. per minute (1000 calories per second).

A related quantity which may be calculated from the coefficient f_0 is the energy released by the combustion of the core. If the rod consists of pure iron or mild steel, its heat of oxidation will be approximately 2900 Btu. per pound,[14] or 830 Btu. per cubic inch. According to Fig. 2 the burn-off coefficient will be 3×10^{-3} cu. in. per ampere per minute. The total heat of combustion may then be computed as follows:

$$Q_{rod} = 3 \times 10^{-3} \times I \times 830 = 2.5I \text{ Btu./min.} \qquad (3)$$

At 185 amp. the energy available from the combustion of the rod will be 465 Btu. per minute (1920 cal. per second).

Combining Equations 2 and 3, it will be observed that the energy available from the combustion of the rod is roughly twice that available from the arc, since the arc voltage will range between 28 and 44 v. (Fig. 1).

$$\frac{Q_{rod}}{Q_{arc}} = \frac{2.5I}{0.037EI} = \frac{67}{E} \approx 1.5 \text{ to } 2.4 \qquad (4)$$

Rate of Cutting Mild Steel

The speed of cutting in its simplest analysis depends on the rate at which the reaction temperature is established at the surface of the plate and within the plate. The reaction temperature itself depends on the mechanism of the cutting process. For carbon steel the process is an exothermic oxidation, which is self perpetuating once the kindling temperature is reached, although the time lag of the reaction tends to propagate the heat downward into the cut much better than upward. For iron this temperature (about 1600° F.) is sufficiently high that heat losses from the surface of the plate and the cooling effect of the incoming oxygen stream tend to extinguish the arc unless preheat is applied to the surface continually. Accordingly, the rate at which the surface of the plate can be heated by the arc to 1600° F. should be the major factor determining the speed of cutting mild steel.

The mathematical theory of heat transfer from the arc to the plate during welding and cutting has been developed by Rosenthal[10–12] and Rykalin,[13] using the concept of quasi-stationary states. In this method the temperature distribution around a uniformly moving arc is studied under the quasi-stationary conditions (stationary relative to the arc itself, but moving with the arc across the plate) which become established when making an infinitely long weld on plates of infinite extent. These conditions are established to a sufficient degree of approximation during the welding and cutting of plates of average size, since the outer edges of most plates remain essentially at room temperature during the progress of the cut.

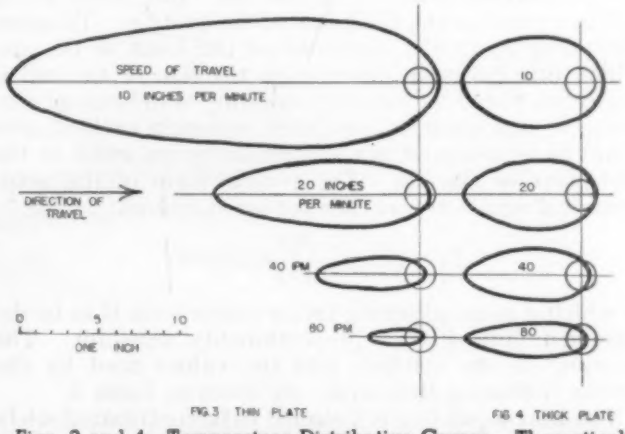
The mathematical solution of the heat flow equations is simplest for a two-dimensional sheet (in practice not over $^3/_8$ in. thick) and for an infinitely thick plate (in practice anything over 4 in. thick), which it is assumed are being heated by a point source of heat. Since the actual arc is of finite area, the solutions obtained by Rosenthal and Rykalin for these two cases are valid only at a distance from the arc, but there their agreement with observed conditions is very good. Close to the arc the agreement is poor. Unfortunately the region of greatest interest in Oxyarc cutting is close to or within the arc. The compromise that is proposed is a semiempirical formula based on the mathematical solution of the theoretical equations. This formula has been made to fit the available data for several thicknesses of plate and two sizes of rod and a wide range of currents, by introducing a factor related to the thickness of the plate. Since this solution lacks a sound theoretical basis, it is hoped that other investigators will endeavor to obtain a rigorous solution of the heat flow equations based on heat sources of finite area, which may lead to a more fundamental formula for the speed of cutting.

The size and shape of the 1600° F. isotherm, as predicted by the theoretical equation for a two-dimensional sheet (see Appendix), is shown in Fig. 3 for various travel speeds of a point source of heat delivering 1000 calories per second to a $^1/_4$-in. plate. The size of a $^3/_{16}$-in. rod has been indicated on the curves for purpose of comparison. Inasmuch as the temperature distribution in the plate after the arc has passed has little effect on the speed of cutting, it will be recognized that the preheating capacity of the arc is represented by the portion of the isotherm ahead of or at least abreast of the center of the arc. From Fig. 3 then it is seen that the preheating effect is becoming vanishingly small between 40 and 80 in. per minute travel speed. If the equation is valid, the upper limit for the cutting rate at that heat input must be something less than 80 in. per minute.

The theoretical size and shape of the 1600° F. isotherm on thick plate (see Appendix) is shown in Fig. 4 for the same conditions as in Fig. 3.

It will be seen from Figs. 3 and 4 that for high rates of travel of a point source of heat the theoretical equations predict that the area of thick plate which can be heated to a given temperature will be larger than the area of thin plate. The fallacy is that for short distances from the arc (less than the thickness of the plate) a thin plate does not function as a two-dimensional sheet and must be considered a three-dimensional plate. The equation for thin sheets therefore does not apply at the fastest travel rates.

The paradox discussed above indicates that the simple heat transfer equations will not be immediately appli-



Figs. 3 and 4—Temperature Distribution Curves. Theoretical Size and Shape of 1600° F. Isotherm on Mild Steel Plate During Welding Runs with Point Source of Heat Delivering 1000 Calories per Second. Circles Show Relative Size of $^3/_{16}$-In. Rod

Table 2

Symbol	Definition	Units	Typical Values: Oxyarc Rod	Mild Steel	Type 308 Electrode
V	Rate of fusion	In./Min.	.....	.....	.....
v	Speed of cutting	In./Min.	.....	.....	.....
f	Proportionality constant	Btu./amp./min.	.....	.....	.....
f_0	Burn-off coefficient	Cu. in./amp./min.	3×10^{-3}	....	1.7×10^{-3}
i	Current density	Amp./sq. in.	.....	.....	.....
T_1	{Fusion temperature	° F.	.....	2760	2568
	{Kindling temperature	° F.	1600	1600	.....
T_0	Room temperature	° F.	68	68	68
C	Specific heat	Btu./lb./° F.	0.107	0.107	0.12
ρ	Density	Lb./cu. in.	0.284	0.284	0.286
Q	Heat input	Btu./min.	.....	.....	.....
E	Voltage	V.	.....	.....	.....
I	Current	Amp.	.....	.....	.....
F	Adjusting factor	None	.....	$8.7g^{1.9}$	.....
k	Thermal conductivity	Btu./In.²/in./° F./Min.	.....	0.0335	.....
g	Plate thickness	In.	.....	....	.....
$K_0(x)$	Bessel function of second kind, zero order	None		See Tables	
b	Proportionality constant	In.$^{-1}$	.....	1.2	.....
λ	Thermal diffusivity	Min./in.²	.....	0.538	.....
r	Radius of rod	In.	.....	.....	.....
δ	Orifice diameter, oxyacetylene tip	In.	.....	.....	.....
d	Measured inside diameter, Oxyarc rod	In.	.....	.....	.....
δ'	Effective diameter Oxyarc rod	In.	$0.78d$	.....	.....
X	Oxygen flow rate	Cu. ft./hr.	.....	.....	.....
ψ	Oxygen pressure	Psi.	.....	.....	.....

cable to the theory of Oxyarc cutting. It is possible that a rigorous solution based on the finite size of the arc will be able to resolve some of the difficulties, but it seems likely that special recognition will also have to be given to the effect of plate size. The equation for thick plate naturally does not involve plate thickness, being based on an infinite plate. But if this equation is the only correct one for fast speeds, then all thicknesses of metal should be cut at the same speed, which is certainly not in agreement with experience.

In order to obtain a semiempirical formula which would correlate the available Oxyarc cutting data, the author has modified the theoretical equation for thin sheets to fit the so-called "best" data points. The choice of the two-dimensional equation was based on the approximate agreement of that equation with the data covering the effect of varying outside diameters of the core, and the general adaptability of the Bessel function $K_0(x)$ in fitting the data on the dependence of cutting rate on current. The following procedure was adopted.

It was assumed that the minimum area of surface which must be preheated by the arc is proportional both to the outside diameter of the rod (and hence to its radius r) and to the thickness of the plate g. To avoid the piling up of the isotherms at the front of the arc, which introduces an error when the size of the rod is neglected,[11] and to gain the resulting simplicity of formula, it was assumed that this minimum preheat area could be represented in the formula by its width at the mid-point of the arc. The general form of the semiempirical equation was then set up as follows:

$$T_1 - T_0 = \frac{FQ}{2\pi kg} K_0(bg\lambda vr) \qquad (5)$$

in which F is an adjusting factor whose form is to be determined, and b is a proportionality constant. The meaning of the symbols and the values used by the author (following Rosenthal) are listed in Table 2.

The heat input Q was assumed to be contributed solely by the electric current. The heat resulting from the oxidation of the core was assumed to be liberated at a distance from the arc, as will be discussed later in the section on stainless cutting. The fraction of the total arc energy available to heat the work was then assumed to be 65%, as derived above (Equation 2). By substituting the experimental data into Equation 5 and plotting the results on log-log paper, the most suitable values for factors F and b were determined. The resulting semiempirical formula for the rate of cutting v was the following equation:

$$g^{0.9} EIK_0(0.647grv) = 1000 \qquad (6)$$

The predictions of Equation 6 are shown in Fig. 5, together with experimental data for mild steel plates taken from Table 1. The agreement at certain points is of course a consequence of the method of adjusting Equation 6 to fit the data, but the over-all agreement, which it will be noted covers a fourfold range of energy, an eightfold range of plate sizes, and two different diameters of rod, is encouraging. A single formula which is able to fit so many data is of considerable help in a number of practical problems. It permits confident interpolation between widespread points following a consistent pattern. It points out certain of the data which should be rejected as being obviously in error or at least not of a quality comparable to the rest of the data. This would seem to be true of some of the cuts on 1-in. plate; the speeds reported are slower than the predictions of Equation 6, so it is assumed these cuts were made with insufficient practice on that size of plate.

Another practical use which has been made of Equation 6 is the prediction of operating conditions for untested sizes of plate. Within the limits of Fig. 5 such interpolations seem quite justified. It is of considerable advantage to the operator to know what speed to expect at a given current setting, as that establishes his mental picture of the technique to be used, and indicates after a suitable calculation what the oxygen flow rate should be.

Rate of Oxygen Consumption

It has probably been noted that the theory in the preceding section takes no account of the oxygen requirements in mild steel cutting. Actually both the inside

diameter of the rod and the oxygen pressure are known to be experimental variables, but since the quality of the cuts in Fig. 5 was fairly uniform, these variables did not affect the results.

The choice of inside diameter for the rod need not be made by guesswork. Suitable orifice diameters have already been determined for oxyacetylene cutting, and recommended tip sizes and oxygen pressures are available from a number of sources. A convenient set of data which will be used for the calculations in this section may be found in the *Welding Handbook*[14] and in the data sheets supplied by the Air Reduction Co. for a style 124 cutting tip.[15]

For quality cuts in mild steel, the tip diameters used in machine cutting and hand cutting are shown in Fig. 6, plotted against the plate thickness g. This diagram is based on the data from the *Welding Handbook* (Table 1, p. 663, and Fig. 4, p 662). The heavy horizontal lines show the range of plate sizes covered by the experimental data so far reported for several sizes of Oxyarc rods.[3] The Oxyarc lines are plotted at levels corresponding to effective orifice diameters, which are computed by a method described below.

Within the range of pressures recommended for the various oxyactylene tips shown in Fig. 6, the oxygen flow rate X in cubic feet per hour and the operating pressure ψ in pounds per square inch may be related by a simple mathematical expression. The data for a style 124 cutting tip are shown in Fig. 7. These points were computed by subtracting from the reported total oxygen consumption the oxygen being supplied to support the combustion of the acetylene preheat flames. The oxygen-to-acetylene ratio was taken as 1.1 to 1, the practical value used in the *Welding Handbook*.

The data points in Fig. 7 seem to belong to a family of curves radiating from $\psi = -11$ psi. oxygen, meaning that for turbulent flow the oxygen volume appears to be directly proportional to $(\psi + 11)$ psi. The dependence of the flow rate on the orifice diameter δ (in inches) may

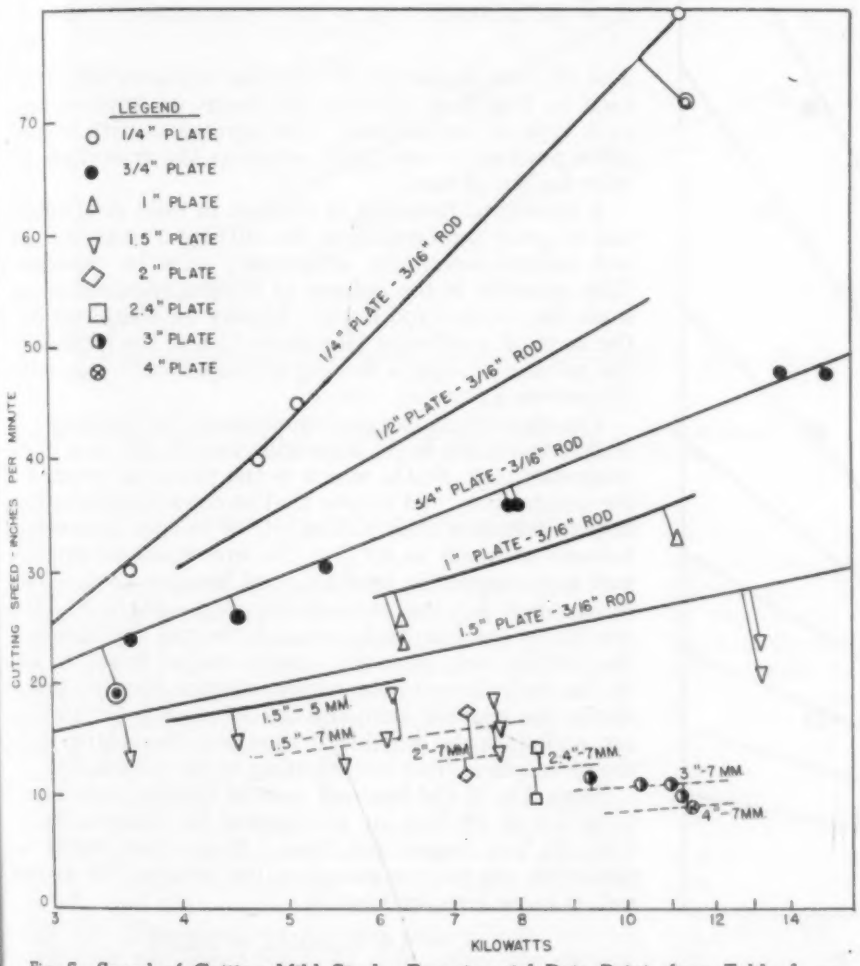


Fig. 5—Speed of Cutting Mild Steel. Experimental Data Points from Table 1, as Identified in Legend. Curves Calculated from Equation 6 for Rod and Plate Thicknesses Shown on Curves

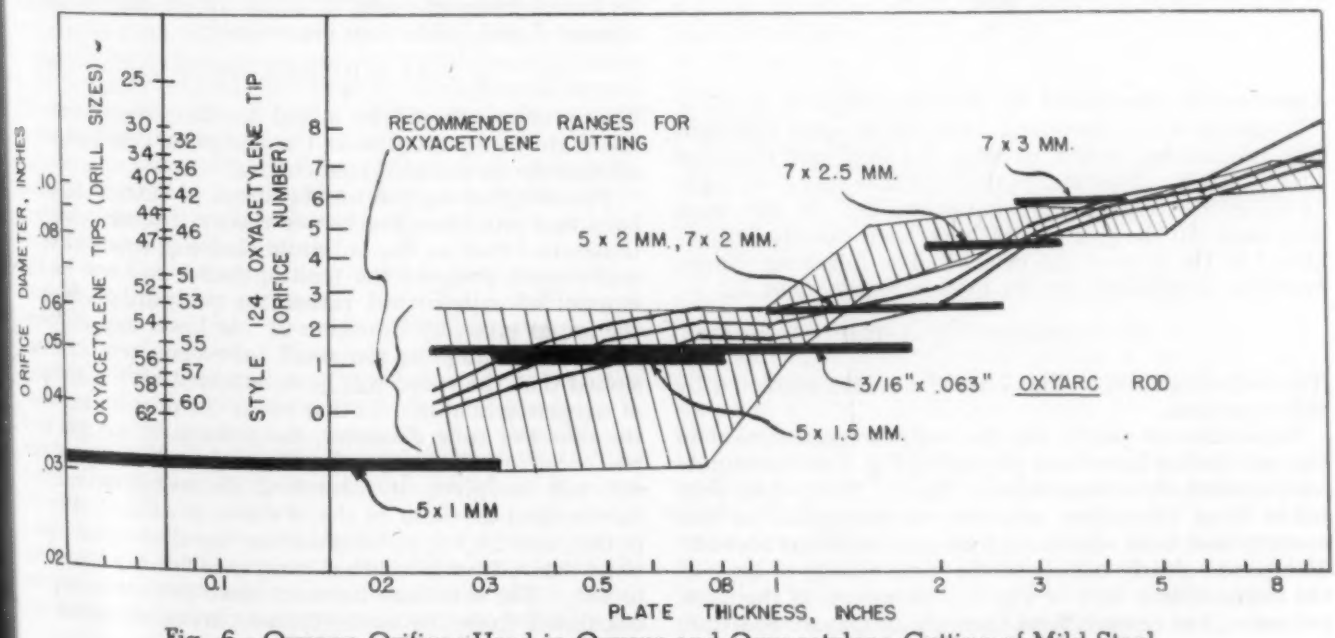

ORIFICE DIAMETER, INCHES
OXYACETYLENE TIPS (DRILL SIZES)
STYLE 124 OXYACETYLENE TIP (ORIFICE NUMBER)
RECOMMENDED RANGES FOR OXYACETYLENE CUTTING
7 x 3 MM.
7 x 2.5 MM.
5 x 2 MM., 7 x 2 MM.
3/16" x .063" OXYARC ROD
5 x 1.5 MM.
5 x 1 MM
PLATE THICKNESS, INCHES

Fig. 6—Oxygen Orifices Used in Oxyarc and Oxyacetylene Cutting of Mild Steel

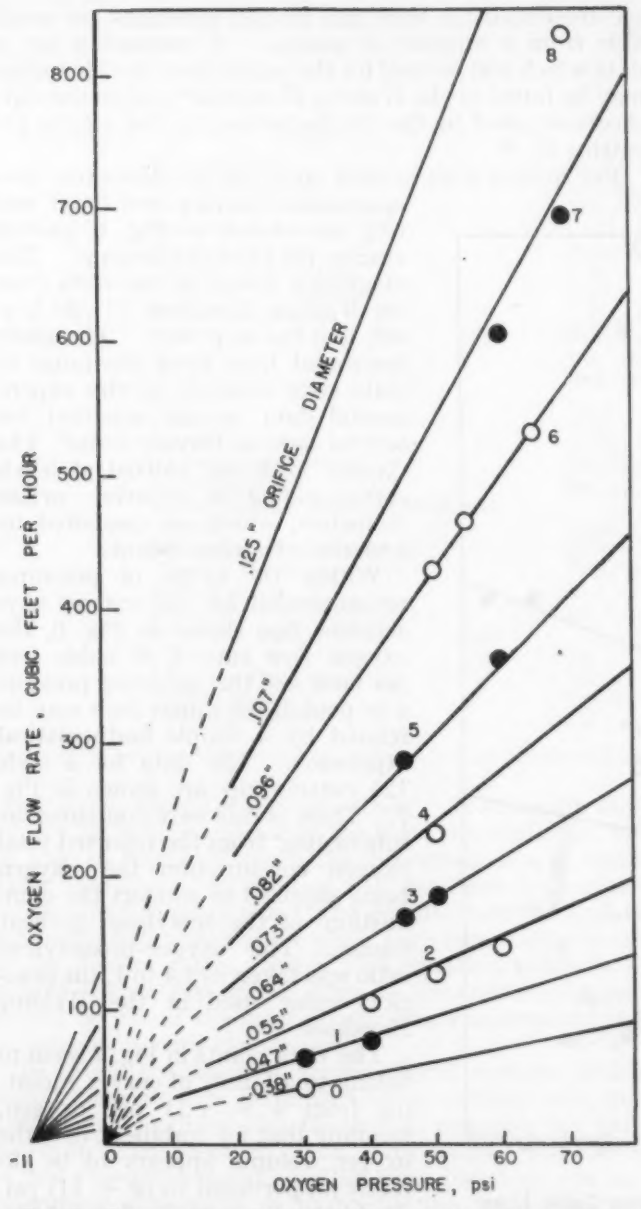


Fig. 7—Oxygen Flow Rates for Oxyacetylene Cutting Tips. Radiating Lines Calculated from Equation 7 for Various Orifice Sizes

therefore be determined by plotting values of $X/(\psi + 11)$ against orifice diameters. On log-log paper a straight line relationship exists, of slope 2.1 and unit intercept at $\delta = 0.038$. This means that the flow rate is equal to $(\delta/0.038)^{2.1}$. This is not unreasonable: if the slope had been 2.0 the rate would have been exactly proportional to the area of the orifice. The following expression thus is obtained for the oxygen requirement X:

$$X = (\delta/0.038)^{2.1}(\psi + 11) \qquad (7)$$

The radiating lines in Fig. 7 are the values predicted by this equation.

Experimental points for the oxygen consumption in Oxyarc cutting have been plotted in Fig. 8 on coordinate axes equivalent to those used in Fig. 7. These data were taken from laboratory experiments performed in this country and from commercial figures published abroad.[3] The points clearly belong to the same family of lines as the oxyacetylene data of Fig. 7. However, at the same pressures, less oxygen flows through an Oxyarc rod than through an oxyacetylene tip of equal inside diameter. The frictional losses in the tube and in the holder reduce the effective diameter of the tube.

When the observed flow rates and oxygen pressures for Oxyarc cutting are substituted into Equation 7, effective diameters (δ') are obtained which turn out to be 0.78 times the measured diameter (d). Substituting the measured inside diameter of the Oxyarc rod for the orifice diameter, Equation 7 becomes

$$X = (0.78d/0.038)^{2.1}(\psi + 11) = (d/0.0487)^{2.1}(\psi + 11) \qquad (8)$$

The effective diameters (δ') are the ordinates which were used in Fig. 6 in plotting the range of application of each type of Oxyarc rod. The agreement with oxyacetylene practice is very good, whereas the true diameters were far out of line.

A numerical quantity of interest in mild steel cutting and of great importance in the cutting of stainless steel and oxidation-resistant alloys may now be calculated. This quantity is the volume of oxygen required to consume the Oxyarc rod itself. It may be computed from the burn-off coefficient (Equation 1) and the formula for the volume of oxygen flowing through the Oxyarc orifice (Equation 8).

The theoretical oxygen requirement for burning 1 lb. of iron is 4.6 cu. ft.[14] This will convert the iron to the magnetic oxide Fe_3O_4, which is the principal product of the combustion. It is true that in oxyacetylene cutting appreciably less than 4.6 cu. ft. of oxygen is required, because as much as 30% or the iron removed from the kerf is incompletely oxidized, and because some oxygen is supplied by the surrounding atmosphere.[14] These conditions are less likely to apply to the combustion of the Oxyarc rod, since any metal eroded from the core by the turbulence of the oxygen stream becomes heated above the reaction temperature on passing through the arc, and since the crucible at the tip of the coating keeps the atmosphere from contributing to the combustion.

From Fig. 2 the burn-off rate of Oxyarc rods is seen to be 3.0×10^{-3} cu. in. per ampere per minute, that is, 0.051 lb. per ampere per hour. From these values the minimum oxygen consumption for burning the Oxyarc rod, in cubic feet per hour, is

$$X = 4.6 \times 0.051I = 0.235I \qquad (9)$$

Combined with Equation 8, this gives the following expression for the minimum oxygen pressure ψ necessary to insure complete core combustion at the operating current I and inside core diameter d:

$$\psi + 11 = 0.235I(0.0487/d)^{2.1} \qquad (10)$$

This pressure should be added to the requirements of the plate being cut just as the acetylene combustion is allowed for in oxyacetylene cutting.

The effect of oxygen on the speed of cutting has not been tied into the quantitative theory. Qualitatively it is assumed that for the optimum choice of tube diameter and oxygen pressure the limiting factor will not be the amount of oxygen, but rather the preheating effect of the arc as given by Equation 6. At lower oxygen pressures or too large or too small tube diameters it is assumed that the speed will be determined by the amount of oxygen available. In that event the relation between the effective tube diameter, the volume of oxygen and the "drag" of the oxygen flow lines along the edge of the cut will be given by standard oxyacetylene cutting curves such as those in the *Welding Handbook* (Fig. 5, p. 664, and Fig. 8, p. 670) and by the theoretical equations derived by Rosenthal (reference 10, Equations 45 to 48). The boundary between these two cases may be calculated from the oxyacetylene curves whenever the permissible drag has been decided on.

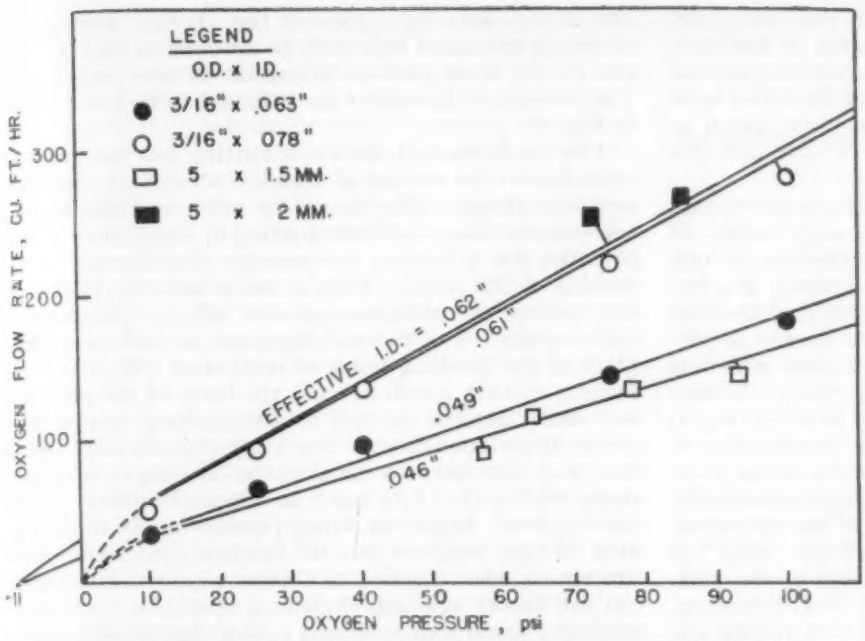


Fig. 8—Oxygen Flow Rates in Oxyarc Cutting. Radiating Lines Calculated from Equation 7 for Effective Inside Diameters Shown on Lines

Application to Stainless Steels and Oxidation-Resistant Alloys

The mechanism of cutting alloys in which a self-sustaining oxidation reaction does not take place is obviously more complex than the mechanism discussed above for mild steel. Various degrees of difficulty will exist, ranging from partially ferrous alloys, in which some oxidation is possible, up to fully "stainless" oxidation-resistant metals and alloys, in which oxidation is prevented by the surface oxide film.

Further difficulty will be introduced by the melting points of these alloys, which in general are higher than the kindling temperature of mild steel. For stainless steel the melting point of the alloy as a whole is over 2550° F., and that of the chromic oxide surface film is 3600° F.[5] The speed of cutting such alloys will be slower than the speed for mild steel, since the rate at which the reaction temperature can be established will be slower. Nevertheless the Oxyarc process is able to cut all of these alloys, many of which cannot be touched by simple oxyacetylene cutting. This greater operational ability of the Oxyarc process would therefore seem to be the result of some and possibly all of the differences existing between the Oxyarc "flame" and the simple oxyacetylene flame. The outstanding factors will be discussed in this section. Some of them have been independently pointed out by the recent improvements in oxyacetylene cutting known as the flux-injection and the iron-powder cutting methods.[8]

The thermal cutting of any metal is fundamentally a melting and ejecting problem. Even if the first step is an oxidation reaction, the rate-controlling step is the melting of the oxide. Therefore, in this section the emphasis will be placed on the process of melting the metal or alloy or oxide along the surfaces of the cut.

If the metal is oxidation resistant, then the edges of the cut must be raised to the normal melting point of the metal and the resulting liquid must be blown clear of the cut. If the metal behaves as mild steel, the metal oxidizes far below its melting point (at a temperature known as the kindling point) converting the edge of the cut into a mixture of low melting oxides which simultaneously are heated to above their melting point by the heat of the oxidation reaction. This makes a fluid slag which is easily washed away by the oxygen stream, exposing a fresh surface of unoxidized metal already heated to the kindling temperature.

Intermediate and more complicated conditions also exist. Partial oxidation will aid the reaction whenever it leads to an oxide mixture of lower melting point than the parent metal. Usually the partial oxidation will contribute some of the heat needed to achieve that temperature. On the other hand, partial oxidation will complicate the cutting whenever the oxide film is higher melting than the parent metal. This is the case with cast iron. By the time the surface oxides have reached their melting point, the temperature of the metal in the vicinity of the cut is above its melting point. When the surface oxides melt and wash away, the molten plate metal also washes away. Oxidation is thus discontinuous and only a portion of the expected energy of combustion becomes available to heat the unmelted portions of the plate. If the metal is by nature nearly nonoxidizing, then the cutting is even more difficult since all of the heat required to melt the surface film must be supplied by the cutting stream. In the case of the chromium-bearing alloys for example, the formation of chromium oxide results in a high melting surface film which is able to prevent further oxidation of the alloy beneath it. Under low-energy cutting conditions the surface of the attempted cut becomes covered by this apparently infusible film of chrome oxide and no cutting is accomplished.

In order to cut the more difficult metals both physical and chemical reactions may be encouraged between the parent metal and special products introduced deliberately into the reaction zone, with the intention of lowering the melting point of the metal or of the surface oxide film. This process is called a fluxing reaction when mineral ingredients of a coating or flux are involved, or when the iron oxide from the oxidation of an iron rod or iron powder is involved. It is called a dilution reaction when liquid iron or iron oxide alloys with the plate metal or alloy oxides. Fluxing and diluting reactions are both used in the Oxyarc process by reason of the composite structure of the rod.

The high temperature needed to melt the difficulty fusible metals and oxides may be obtained by using slow rates of travel, intense sources of heat or improved methods of transferring the heat. All of these methods are used in Oxyarc cutting, but the last one is considered the most important in explaining the cutting of stainless alloys. This improved heat transfer method results from the liberation of a great amount of energy throughout the length of the arc-and-oxygen stream as a result of the combustion of the core. In the Oxyarc cutting of stainless alloys it is apparent that the interior of the plate is being heated far more effectively and directly than the simple bead-on-plate theory of heat transfer in welding would predict. Examination of cuts in all kinds of alloys shows that the plate is not melted by brute force from the surface alone, but seemingly is heated along the entire leading edge of the cut (unless the plate is thicker than the maximum depth which can be cut in a single pass). The explanation of this behavior lies partly in the action of the oxygen stream in

directing the heat of the arc downward into the plate, and largely in the kinetics of the oxidation of the core. The combustion of iron is not an instantaneous process. The time delay in the formation first of FeO and later of Fe_3O_4 and Fe_2O_3 results in a reaction zone which at high oxygen velocities extends a considerable distance from the arc.

The total energy present in the arc-and-oxygen stream is considerably greater than the arc energy alone, as shown earlier in Equation 4. The distribution of this energy is schematically shown in Fig. 9, which is a hypothetical cross section through the kerf and the rod during the process of cutting. The arc energy is pictured as the truly concentrated heat source which is responsible for heating the surface of the plate. It does not seem necessary to the theory of mild steel cutting to postulate any preheating effect from the combustion of the core. That energy is rather transferred to the plate further down in the cut, as indicated diagrammatically in Fig. 9. This heats the leading edge of the cut to the melting temperature so rapidly that little "drag" is evidenced in the flow lines along the edge of the kerf. At the same time the fluxing provided by the coating, and the diluting action of the oxidized core reduce the melting point of the surface oxides so that the mixture becomes completely fluid at the temperature provided by the arc-oxygen stream.

The concept above is an important one which merits emphasis. A contemporary article on flux-injection cutting[8] is quite in error on this point. In reviewing alternate methods of cutting stainless steel, this article says that the Oxyarc method "is not unlike the use of extreme preheat." This error is repeated in a later sentence, which states: "no high temperature protective shield of burning gases is forced continuously into the kerf to minimize the chilling of slag." Actually the combustion of the Oxyarc core is doing exactly that. This misconception in the case of the article quoted is perhaps partially the fault of a schematic drawing which the article uses to represent the Oxyarc process: it shows an uncoated rod, with no crucible to seal the oxygen to the work and no indication of core combustion. The conditions in reality are believed to be those shown in Fig. 9.

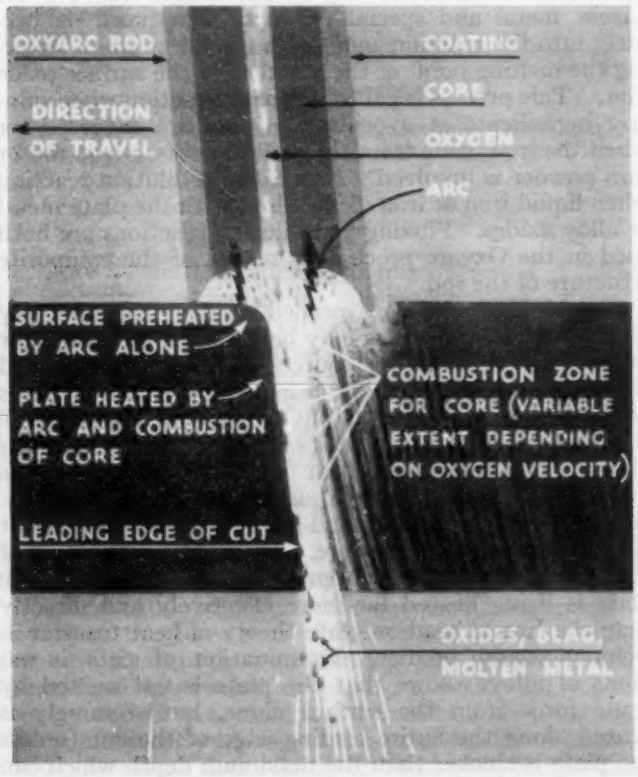


Fig. 9—Schematic Diagram of Oxyarc Cutting. Section Through Oxyarc Rod and Metal Being Cut

The mathematical theory of cutting has not yet been extended to the cutting of stainless steels and oxidation-resistant alloys. The theory for mild steel discussed in the sections above and culminating in Equation 6 merely provides for a certain temperature distribution at the surface of the plate. This is not a suitable theory for the cutting of oxidation-resistant alloys. Substitution into Equation 6 of the melting point of such an alloy in place of the kindling point of mild steel will predict too rapid a cutting speed, because the body of the plate will not have become heated to the melting temperature under those conditions. For truly nonoxidizing metals the heat necessary to develop the melting temperature down within the plate must be supplied entirely by the cutting rod. Equation 6 may possibly apply to the cutting of thin sections but its fundamental assumptions are wrong when applied to thicker plates. The mathematical theory of stainless cutting should be based on an extended linear source of heat rather than a point source.

Such a theory has already been worked out by Rosenthal,[10] but unfortunately not for the complicated conditions prevailing in cutting oxidation-resistant alloys. The fundamental equation is similar in form to the theoretical equation for a two-dimensional sheet, but it requires integration over the entire length of the heat source. The integration can be performed accurately if the heat source is constant throughout its length; this integration then leads directly to the equation for the isotherms in a thin sheet, for if heat losses through the surface are neglected these conditions are essentially two dimensional with respect to the heat source. The integration may be performed as a series of summations if the heat source is assumed to vary uniformly from a maximum at the upper surface of the plate to a minimum at the lower surface. Rosenthal has obtained an approximate solution for this case, which may be related to the oxyacetylene cutting of mild steel; however, the solution does not agree with reported data unless a correcting factor is applied. In the present problem a somewhat similar solution seems to be indicated, with the heat source tapering off from the intense energy of the arc to the more moderate temperatures of the gases and slag discharging from the bottom of the cut.

Since the exact size and shape of the heat source are still a matter of speculation, the author has been discouraged from attempting a numerical solution for the cutting of stainless alloys. It is hoped that some day at least an approximate solution will become available, in order to smooth experimental values and interpolate between widespread points as has already been done for mild steel cutting. At any rate a start has been made in that direction by describing the qualitative aspects of heat generation, melting, fluxing, diluting and mechanical ejection.

Economy of Operation

An immediate practical application of the theory developed in this paper would be an investigation of the economics of cutting. It is not the author's intention to inject actual cost figures into the present discussion, but a few general observations are in order.

Equations 1, 6 and 8 may be used to compute the cost of cutting under various operating conditions. It is obvious that as soon as arbitrary values are assigned to the cost of rods, the price of oxygen, the cost of labor and the time required by the operator to change rods in the holder, a calculation can be made of the cost of cutting

per foot of plate or per unit operation. The variables in such calculations are the current I, the oxygen pressure ψ and the inside and outside dimensions of the Oxyarc rod. When the underwater cutting rod is examined in this light it is seen to be less economical to operate than rods of smaller outside diameter. This deduction is an encouraging test of the theory, for it is understood to agree with the preliminary experiments conducted by the U. S. Navy. Perhaps it should be pointed out that for underwater cutting the larger rod was finally specified not for economy but for length of life: it was of prime importance that the diver be freed as far as possible from the task of changing rods. For open-air cutting the greater importance of economy has favored the use of the smaller rods.

Another use of Equation 1 involves the relation between burn-off rate and the melting or kindling temperature. Equation 1 shows that a noncombustible rod of high melting point, say a stainless steel or nickel-base alloy, will have a proportionately slower burn-off rate than a mild steel rod. This observation immediately raises the practical question: will such a rod be a more economical tool to use? The question is outside the scope of Equation 1, but the answer can be given from other knowledge. For the stainless type of rod to be more economical, two conditions must be fulfilled: first, the increased cost of the core must not offset the gain in lifetime of the individual rod, and second, the speed of cutting must not be adversely affected. Actually neither of these conditions is fulfilled. The expected increase in rod life is less than twofold, while the increase in cost is several times that. The speed of cutting furthermore is definitely decreased. Early experimenters with the underwater arc-oxygen method used brass and cast-iron tubes,[1] but these tubes were found to be inefficient. Stainless steel tubes are understood to have been investigated during the development of the modern underwater electrode and to have been found unsatisfactory in comparison with mild steel. Each of these efforts to use oxidation-resistant core metal resulted in reduced speed of cutting and far higher costs.

Some comment should also be made on the subject of oxygen consumption. When using the present mild-steel Oxyarc rods to cut stainless or nonferrous metals, the most economical oxygen pressure will be but little greater than the minimum pressure required to consume the rod (Equation 10). Even at the lowest pressures the oxygen stream seems to have sufficient force to fairly easily clear the molten metal out of the cut.

According to Equation 10, for one of the commercial brands of Oxyarc rods in which $d = 0.063$, the pressure ψ should be 7 psi. at 130 amp., 14.5 psi. at 185 amp., 27 psi. at 275 amp., and so on. The lowest pressures which have been recommended for commercial cutting of stainless alloys with this particular Oxyarc rod (based on experimental tests only and not on Equation 10) are "10 to 15 psi.," except for $^1/_4$- and $^1/_2$-in thick chrome-nickel steels, straight-chrome steels, Monel and nickel; in these cases 3–5 psi. and 5–10 psi. were recommended for the $^1/_4$- and $^1/_2$-in. thicknesses, respectively, using 175 to 185 amp. The general recommendation of 10–15 psi. minimum seems quite reasonable in the light of Equation 10. The use of less than 10 psi. of oxygen for the special alloys would not be in keeping with Equation 10, but on $^1/_4$- and $^1/_2$-in. plate it may be difficult to detect any difference between 5 and 10 psi. It will be recognized that in cutting thin plates with rapid oxygen flow the heat of combustion of the core may be liberated too far from the tip of the rod to be transferred effectively to the plate, whereas at lower oxygen flow rates the reaction zone may be much more concentrated and thus may be able to heat up the plate more effectively, even though the incompleteness of the combustion makes less heat available in total. An exact experimental study of the optimum cutting conditions should be made, in which the results are interpreted in the light of Equation 10.

Future Research Needed

The future work which is needed in connection with the theory of Oxyarc cutting lies mainly in the field of mathematics. Physical measurements are needed to determine the length of the combustion zone for the oxidation of the rod and the heat distribution within that zone, and yet even these values may be capable of theoretical calculation. It seems reasonable to hope that a rigorous development of the theory of heat transfer from an arc of finite size to the surface of plates of given thicknesses will correlate the existing data for mild steel cutting and possibly justify some of the assumptions the author has made in this paper. Similarly it is to be hoped that a rigorous treatment of the propagation of heat ahead of an advancing "flame" of finite length and variable heat content will correlate the existing or future data for cutting oxidation-resistant alloys. In this latter case more exact data will perhaps be necessary before the theory can be tested. There is already evidence appearing in field tests that the early data, obtained without benefit of theoretical guidance or prior experience, were lower in speed than need be accepted.

The present statement of the theory of Oxyarc cutting covers the qualitative aspects of the process and some of its quantitative aspects. When the mathematics of stainless cutting has been worked out, it is believed that the theory will be able to predict the optimum conditions for efficient quality cutting of any commercial alloy whose physical constants are known or can be determined.

Summary

The Oxyarc process is an arc-and-oxygen cutting method capable of piercing, cutting or gouging any metal or alloy. The mechanism by which it operates has been analyzed as accurately as possible in this paper, in order to develop a qualitative and quantitative theory of its operation.

The heart of the process is the Oxyarc rod. This is a flux-coated metallic tube through which oxygen and the electric current are conducted to the surface of the work. The dimensions and composition of the core of the rod determine the economy of cutting. They control the dimensions and quality of the cut, the rate of burn-off of the rod and the rate of consumption of oxygen. The ability of the process to cut oxidation-resistant alloys results from the use of a mild steel core, the combustion of which contributes the additional heat needed to melt such alloys. The coating on the rod is similar to the coating of a mineral-type arc-welding electrode. The coating performs the important functions of stabilizing the arc for a.-c. or d.-c. operation (the oxygen stream tends to blow out an unstable arc), of sealing the arc and the oxygen to the work (by forming an insulating crucible which the operator keeps in contact with the work), and of fluxing the metal and oxides from the cut.

A quantitative mathematical theory of cutting has also been attempted. The theory is still in various stages of development depending on the complexity of the problems studied.

The rate of burn-off of the Oxyarc rod is directly proportional to the intensity of the electric current and the cross-sectional area of the core. For simple cutting the burn-off rate is 0.003 cu. in. per ampere per minute. For piercing and gouging, the rate is somewhat faster.

The energy supplied by the arc to the surface of the cut ranges from 1.0 to 1.6 Btu. per ampere per minute (0.037 Btu. per watt per minute). This is sufficient to explain the speed of preheating mild steel. The heat liberated by the combustion of the core is 2.5 Btu. per ampere per minute, or approximately twice the energy available from the arc.

The rate of cutting mild steel depends on the rate at which the kindling temperature (1600° F.) can be established on the surface of the plate. A semiempirical equation has been written for the speed v of cutting plates of thickness g with Oxyarc rods of outside core diameter $2r$, as follows:

$$g^{0.9}EIK_0(0.647grv) = 1000 \qquad (6)$$

in which EI is the current in watts and $K_0(x)$ is the Bessel function of the second kind and zero order. The equation is partly based on the theoretical equations for the temperature distribution about an electric arc during long welding runs on thin and thick plates of infinite width. The equation agrees with the available cutting data for a wide range of plate thicknesses, rod diameters and arc energies.

The rate of oxygen consumption depends on the inside diameter of the Oxyarc rod and the oxygen pressure. The effective orifice size of the tube is 0.78 times the inside diameter. The correct oxygen pressure ψ for a given plate size may be calculated from the flow rate X used in oxyacetylene practice, using the equation

$$X = (d/0.0487)^{2.1}(\psi + 11) \qquad (8)$$

in which d is the actual inside diameter of the rod. The minimum volume of oxygen needed to completely consume the Oxyarc rod at a given current value I is $0.235I$ cu. ft. per hour. The minimum oxygen pressure ψ is given by the equation

$$\psi + 11 = 0.235I(0.0487/d)^{2.1} \qquad (10)$$

The mechanism of cutting oxidation-resistant alloys is more complex. Qualitatively, the process involves fluxing and diluting actions (which lower the melting point of the surface oxide film at the leading edge of the cut) and an effective heat transfer method resulting from the nature of the arc-and-oxygen stream projecting from the tip of the Oxyarc rod. The time delay in the combustion of the core and the action of the oxygen in directing the heat of the arc downward into the cut create an extended heat source which readily melts the metal and oxides all along the leading edge of the cut. A quantitative picture of stainless cutting has not been attempted.

The future research needed to improve this preliminary theory of cutting is largely mathematical. New experimental data, which will meanwhile be examined in the light of the present development, will undoubtedly become available for testing the future advances of the theory.

APPENDIX

The equation for the isotherms in a two-dimensional sheet is given by Rosenthal[10, 12] in the form

$$T - T_0 = \frac{Q}{2\pi kg} exp(-\lambda v\zeta)K_0(\lambda vr) \qquad (A)$$

in which ζ is a moving coordinate measuring distance from the center of the arc along the direction of motion, and r is a radial coordinate measuring distance from the arc in any direction. The exponential expressions are the natural exponential e^x and the Bessel function of the second kind and zero order, $K_0(x)$. The various constants must be expressed in consistent units. Suitable values in the centimeter-gram-second system are listed by Rosenthal; converted values in the English system as used in this paper are given in Table 2.

The equation for the isotherms in an infinitely thick plate is given by Rosenthal in the form

$$T - T_0 = \frac{Q}{2\pi kr} exp\ (-\lambda v\zeta)\ exp\ (-\lambda vr) \qquad (B)$$

in which the symbols have the same meanings as in Equation A.

The half-width of the isotherms at the mid-point of the arc, that is, the width at 90° to the direction of travel, is given by the value of r when $\zeta = 0$. By basing the semiempirical equation for the speed of cutting on the half-width of the kindling temperature isotherm the equation is simplified through the elimination of the term in ζ. The form of Equation A appears more promising than Equation B for fitting data for various sizes of plate because it already contains the plate thickness g. However, this is not necessarily an advantage since the plate thickness will be arbitrarily introduced into the exponential term in order to obtain semiempirical Equations 5 and 6.

The general form of the semiempirical equation (see Equation 5) is obtained from Equation A by setting $\zeta = 0$, introducing the plate thickness g and an adjusting factor b into the Bessel function $K_0(\lambda vr)$, and adjusting the resulting equation to the experimental data by use of a second factor F.

The most suitable value for the constant b for each size of plate was obtained by substitution of the experimental data into Equation 5. In order to avoid simultaneous equations, the equation was forced to pass through a reliable data point at low current and then by trial the value of b was determined which brought the equation into line with the high current data. Finally, comparing all sizes of plate, it appeared that the value of b which fit the data best was 1.2. The exact value of b is not very critical, a 10% variation giving curves which still fit the data fairly well.

The factor F was then determined by substituting the experimental data into Equation 5 with $b = 1.2$, and plotting the values of F against the plate thickness g on log-log paper. A simple straight line relationship seemed to be indicated, with slope 1.9 and unit intercept ($g = 1$) at $F = 8.7$. The expression for F is thus

$$F = 8.7g^{1.9} \qquad (C)$$

The adjusted form of Equation 5 is then

$$T_1 - T_0 = 1532° = \frac{8.7g^{1.9}(0.65)0.057EI}{2\pi kg}K_0(1.2g\lambda vr) \qquad (D)$$

From this, Equation 6 follows on substituting the numerical values of k and λ and consolidating the constant terms.

It should be noted that the use of factors for Q other than the 65% figure actually used would have no effect on the final form of Equation 6, since that would only change the coefficient (8.7) in factor F (Equation C). By the same token the agreement of the semiempirical equation with the experimental data has no bearing on the validity of the assumption that 65% of the arc energy is available to heat the plate.

The presence of the plate thickness g in the numerator of Equation D may seem confusing. It does not mean that thick plates are hotter than thin plates. The presence of the plate thickness in the Bessel function K_0 exactly balances the total expression and adjusts it to the experimental data, a fact which will be recognized from the method used to compute factor F.

Acknowledgments

The author is very grateful to the Arcos Corp. for permission to publish this paper, and to many members of that organization for helpful criticisms and suggestions. In particular the author wishes to thank R. David Thomas, Jr., for guidance and encouragement, Anton L. Schaeffler for many constructive criticisms and R. C. Silver for the preparation of the figures.

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Composite Alloy Fabrication with the Hidden Arc*

By H. E. Cable†

THE properties of the Hidden Arc process for depositing and joining alloys of poor weldability but good service qualities in resistance to wear, abrasion and corrosion opens a new field metallurgically. The high deposition rate, freedom from operator discomfort in working on preheated material, accurate control of deposit chemistry and the physical contour of the deposit improve on many previous hard surfacing applications and extend the field for the hard-surfacing idea to many new products.

The oldest industrial or commercial applications of arc welding were in the repairing of breaks in metal pieces and in replacing abraded or worn material on the surface of a metal piece. The success of early attempts to use the arc in this manner was often questionable and sometimes still is when the type of metal to be repaired or resurfaced is of poor weldability. However, proper technique in the application of the right electrodes, generally of the austenitic type, to repairing breaks in alloy steels and proper application of the right wear-resistant electrodes has been very successful in many instances for some years past.

The Hidden Arc as a fully automatic welding process in which current and rate of wire feed, voltage, travel speed and direction are all mechanically controlled is not generally applicable to repairing breaks which are normally nonuniform. The recently introduced Manual Lincolnweld in which only current or rate of wire feed and voltage are mechanically controlled with direction and rate of travel under manual control, gives promise in this field.

In the field of replacing worn or abraded or corroded metal the Hidden Arc offers many advantages over manual shielded arc welding in some applications and especially in the related application of composite alloy fabrication wherein a superior quality of alloy composition, usually at higher cost per pound, is applied to only a part or surface where its superior resistance to abrasion or wear, corrosion or impact enhances the serviceability of the piece.

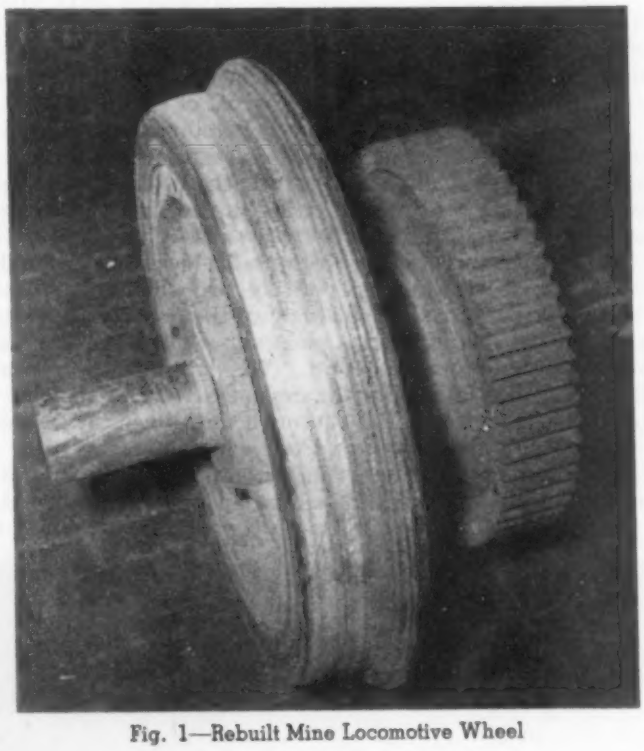

Fig. 1—Rebuilt Mine Locomotive Wheel

The particular virtues of the process are probably best brought out by illustration in the description of some successful applications.

Probably the most common cause of failure both in the repair of fractures and in surfacing is underbead cracking and embrittling of readily hardenable alloys; in fact it seems that most any alloy, other than the austenitic alloys, which is resistant to abrasion, wear or corrosion is

* Scheduled for Twenty-Eighth Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 19, 1947.
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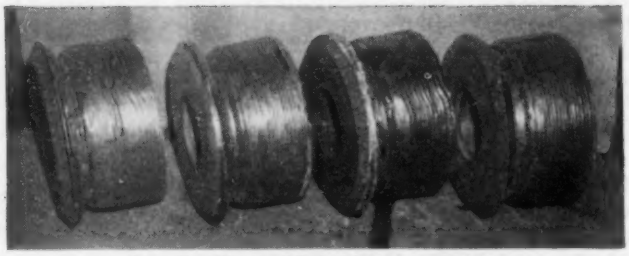


Fig. 2—Flanged Wheel Forming Rolls

so sensitive to hardening as to be classed as of poor weldability.

Our first example to be considered is mine locomotive wheels (Fig. 1). Such wheels have been rebuilt by welding, both manual shielded arc and the open automatic arc.[1] No previous shielded automatic process seems to have been able to justify itself in this usage in the ultimate analysis on the basis of economics.

Most mine locomotive wheels and tires offered today are of an ordinary medium-carbon or high-carbon analysis of poor weldability. This is typical of many other pieces in which no one seems to have conclusive proof that it is the best analysis for the service. Nor do we claim to have found in our limited experience the best alloy but we have found one somewhat better in serviceability which is being applied to rebuilding with substantial economies over replacement.

This paper is not intended to discuss in detail the chemistry or metallurgy of these applications. The foregoing statement is made to bring out the possibilities of developing better serviceability in a product or piece with further economies both as the result of improved cost-service ratio and by indirect savings in the cost of replacing at less frequent intervals which, in many cases, can exceed the savings possible on the cost of the piece itself.

Steel of 0.85 carbon is of poor weldability and normally requires preheating. The rate and uniformity or distribution of heat application with the Hidden Arc are such as to quickly bring the wheel up to stress-relieving temperature. Furthermore, the stress-relief temperature with this process is substantially lower than would be required with other types of arc shielding. Undoubtedly the complete shielding of the arc from hydrogen and the fluxing of the molten pool by this process are responsible to some extent. We would mention here that a substantial part of the carbon content of the electrode is lost even with this thorough shielding as are some other alloying elements to a lesser extent.

A similar yet markedly different application is found in crane wheels where the loading is principally normal to the rail, whereas the mine locomotive wheel is required to exert maximum tractive effort in ratio to wheel loading.

Another related yet very different application is the surfacing of the wheel-forming rolls (Fig. 2) used in rolling flanged steel wheels such as the mine locomotive wheels. These are surfaced with a hot forging tool steel which would be too expensive for good economics if the piece had to be made entirely of this steel. As a facing material its performance is most remarkable.

Wear rings on drill pipe used in the rotary drilling of wells is another example of an application previously done with manual arc welding which is done better and cheaper by the Hidden Arc.

Gates or disks and seats of valves subjected to corrosive or erosive action are being faced better and cheaper by this process.

Because of the relative freedom from hydrogen and some other aspects of this Hidden Arc the sensitivity of these hardenable steels to cracking is lessened. We find that we can make perfectly sound deposits of high-alloy content at such low preheat temperatures as to induce high quench hardness in the deposit without cracking. This has great significance in the rebuilding, or building, of a rolling mill back-up roll. These heavy rolls take the bending load and the crushing load of the much smaller diameter work rolls. They must have great tensile and fatigue strength in the core or mandrel to resist the bending action. The surface must be hard to resist the crushing action under enormous straight-line loadings. The subsurface must be hard enough to support the surface. The conventional back-up roll analysis is a compromise of these requirements in a massive casting which cannot be subjected to more than a very mild quenching action. It must therefore have high-alloy content and this rapidly increases the "per pound" cost of this great mass and decreases its weldability.

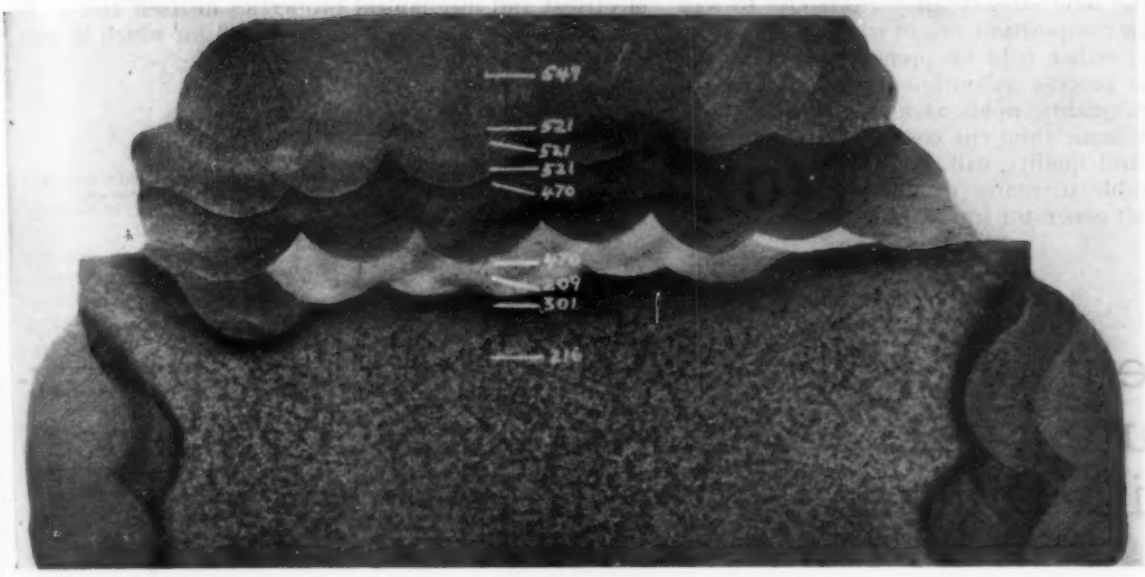
Spalling out of pieces of the surface of these rolls is a common cause of their failure in service. Most roll experts agree that the basic cause of spalling is the work hardening of the surface of the roll to such an extent that a shearing stress is set up between the work-hardened surface layer and the adjacent sublayer which causes failure in this plane and spalls out pieces of the surface layer.

It is believed that quench hardening of the surface layer during deposition followed by a mild draw obtained as subsequent layers are deposited will give a harder surface with less alloy which will be relatively less hardened by working. In this way there will be a lesser difference between the surface hardness and that of the supporting layer for a given amount of working. This means more

Fig. 3—Altered Structural Blooming Mill Roll

	C	Mn	Si	Cr	Mo	W	Ni	V
Cast steel base	0.79	0.65	0.32	0.85	0.42	..	0.10	0.02
1st pass; L-60 electrode	0.15	0.20	0.03	..	..	..	..	..
Subsequent passes X-1837 Electrode	0.35	0.35	1.00	5.00	..	1.35	..	..

Base Preheated to 400° F. for Welding



Firth Hardness Spaced at 0.040 In.

1—549
2—521
3—549
4—521
5—521
6—521
7—521
8—521
9—470
10—470
11—470
12—470
13—470
14—470
15—470
16—209
17—209
18—301
19—278
20—249
21—202
22—216
23—189
24—202

Firth Hardness Readings Taken Every 0.040 In. from Approximate Center of Last Pass Into Bass Metal

Fig. 4—Macrograph of Section Through High-Alloy Deposit

tonnage rolled between roll dressings which is an economy. Furthermore, while our present efforts at rebuilding are limited by the poor weldability of the base metal of the roll, this will be corrected and further economies obtained when the roll is fabricated from the start with a mandrel of good weldability and having maximum toughness. It can be stress relieved, normalized or heat treated as desired. On such mandrel we will deposit appropriate subsurface and surface layers of alloys and quench them during deposition to obtain maximum wearing values. It will be possible to rebuild such rolls almost indefinitely.

This has been done in the case of strip coiler rolls.[2] These coiler rolls run in a basket or holder which presses them against the strip to keep it tight and straight as coiled. The rolls are small in diameter for their length. The conventional cast coiler rolls are high alloy as they must be very hard and smooth to avoid marking the strip. Coiler rolls fabricated by depositing a high-speed tool steel on a 45–50 carbon forged mandrel have given excellent service and are now standard in several mills.

Edge rolls in slabbing mills which are subject to severe wear have similarly been completely fabricated with remarkably improved serviceability and economy.

Numerous types of rolls used in less exacting service are being very economically reclaimed such as cold-reduction rolls and back-up rolls on which journals are rebuilt; passes are altered on structural shape rolls (Fig. 3) and such pieces as a large head shear eccentric.

On the first large roll rebuilt at Jones & Laughlin's Pittsburgh Works the spalled roll was turned free of spalls and all visible cracks which resulted in a 46 in. diameter on the working face. Normal working diameter is 52 in. so it was decided to rebuild to finish that dimension. This required 18 days of continuous operation during which time approximately 13,000 lb. of metal were deposited by one welding head. It was intended to deposit approximately $^3/_8$-in. of finish metal but when the roll was turned it cleaned up all but a few scattered streaks at $52^1/_2$-in. diameter with only about $^1/_8$-in. average finish metal removed. The smaller pieces are regularly deposited to $^3/_{16}$-in. finish metal and expert operators hold within $^1/_8$-in. consistently.

Runout table rollers for some service are not machined at all.

Many of the mine locomotive wheels have only the flange machined.

The wear collars on drill pipe are of course not machined and there are many other instances where the surfacing metal is deposited to such smooth, accurate contour as to require no further finishing. Where this is possible there is even greater economic advantage.

It is mentioned above approximately 13,000 lb. of metal were deposited on the J & L back-up roll in 18 days of welding with one automatic head. There are presently two heads on this setup which reduces time required for a given deposit to about half and has the further advantage of maintaining temperature in the work with less auxiliary heating.

The use of direct current on these applications permits a high proportion of admixture between electrode and base metal by the use of electrode positive polarity whereas maximum deposit rate is obtained using electrode negative. On these round pieces the deposition rate is limited by the diameter and mass of the piece. We have run about 0.9 lb. per minute with one head on large back-up rolls and experience has taught us how to deposit a smooth, uniform bead at high deposit rates.

In the case of welding on high-alloy pieces we have accomplished the transition to another analysis by using a

mild steel electrode to alloy with the base metal beneath and the alloy deposit on top (Fig. 4). Generally speaking the effect of alloying with the base metal is found in the first three layers of deposit with the fourth and subsequent layers approximately stable in analysis as weld metal.

A further obvious advantage of this process is that the operator need not work in the high temperature at which these high alloys need to be welded.

Another type of composite fabrication is the use of this process with either mild steel or alloy electrodes to join pieces of dissimilar composition, one of which usually is of poor weldability, either cold or preheated. Here the properties of the process as outlined make for reproducibility of high-quality welds at low cost which add value and at the same time cut cost. It appears that such economies and quality will make composite alloy fabrication desirable in many production applications such as the aircraft generator frame, plowshares and conveyer and stoker screw flights, some of which are fabricated at the firebox end with chromalloy for heat resistance. Stainless sandwiches and bimetal strips are welded together by this process prior to rolling to size.

The most advanced trend in surfacing with alloys is the use of fabricated electrodes wherein the desired alloy deposit is alloyed in the arc from semirefined ores at substantially lower cost than by using the finished alloy wire. One of the oldest applications of this type is "Lincolloy" which is a copper-iron alloy having a good combination of electrical and mechanical properties in itself and a very low resistance contact with the steel on which it is deposited.

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Comment on Article "A Comparison of Low-Pressure Vessels Constructed in Compliance with Different Codes or Regulations"*

By R. K. Cadwell†

The Liquefied Petroleum Gas Tank Manufacturers' Association would like to call attention to the following information additional to that given in the above article, with particular emphasis on the author's statement in the first paragraph that "A purely statistical analysis will hardly tell the whole story, sometimes 'one good reason why' is worth a good many figures."

Mr. Cecil states that "Narrowing the subject down to considering only containers for liquefied petroleum gases will practically limit comparison of containers to those constructed in accordance with either I.C.C. Specifications or the A.S.M.E. Code or the A.P.I.-A.S.M.E. Code. These standards came into being in the order enumerated, beginning with the I.C.C. Specifications, the early part of this century." The inference apparently being that the date of inception of the code would give that code the advantage over later codes by reason of a longer period of practice. However, liquefied petroleum gases have not been in use on any commercial scale for more than fifteen years and it has been only the last few of these that propane or mixtures requiring higher vaporizing pressures have been handled to any large extent.

Mr. Cecil is right when he says "A comparison of the relative merits of these different types of containers becomes desirable when it is proposed to substitute one type for another, for example, placing an I.C.C. container in stationary service—either temporarily or otherwise. He does not call attention to the fact that the I.C.C. container was designed solely for a shipping container and not for a stationary storage where it ceases to be subject to the periodic inspection required by I.C.C. Specifications which have kept it a "safe" package for shipping.

Mr. Cecil continues, "Mere thickness of the steel in the wall of a container cannot be the yardstick for comparison." He points out that steel specifications for I.C.C. require only a maximum yield of 70% with no minimum requirement, while the other codes require a minimum of 50% with no maximum requirement. It should be pointed out that 70% of the ultimate tensile for the yield point is so high and would result in such a brittle steel that this figure has no meaning with respect to ductile shells. Such a high percentage for yield point in steels specified by A.S.M.E. and A.P.I.-A.S.M.E. codes is unheard of on mill reports.

Mr. Cecil proceeds to a comparison between an I.C.C. 4B240 container and an A.P.I.-A.S.M.E. container built for 240 psi. working pressure in which he attempts to show that in the vessels with seamless shells the shell thicknesses are alike within 2%. He does not mention the fact that the I.C.C. regulations for maximum safety valve setting on the 4B240 is 375 psi., initial opening, with full opening at 425 psi., which as far as safety is concerned, makes the 4B240 equivalent to a 375-lb. vessel, whereas the maximum safety valve setting on the A.P.I.-A.S.M.E. or A.S.M.E. U201 vessel under consideration is 240 lb.

The 240-lb. rating of the I.C.C. container is based on the vaporizing pressure of the liquefied petroleum gas at 70° F. The basis for establishing working pressure on the other various codes and regulations is the vaporizing pressure of the liquefied petroleum gas at either 100 or 130° F., as these temperatures are normally encountered. The I.C.C. Regulation P303 (j) (4) specifically states that the pressure of the cylinder at 130° must not exceed one and one-fourth times the service pressure for which the container is designed. In other words, the 4B240 is a 300-lb. vessel with a safety valve setting which

(*Continued on page 922*)

* Article by R. E. Cecil, published in the May 1947 issue, THE WELDING JOURNAL, pp. 431–433.

† President, California Liquefied Petroleum Gas Tank Manufacturers' Association.

Arc Welding of Copper and Copper-Base Alloys*

By F. E. Garriott†

THE welding of copper and copper-base alloys is a very comprehensive subject. In terms of the iron-base metals, it would be equivalent to covering the entire field of mild steel, low-alloy, high-tensile steel, stainless steel, tool steel and hard surfacing alloy welding. Therefore, this discussion will be confined primarily to the arc welding of the copper alloys used most extensively in industry today.

There are probably as many different alloys of copper available to the designing engineer as there are iron-base metals. However, information regarding the properties, and especially the weldability of the copper-base alloys, is considerably less extensive. General knowledge is fortunately increasing rapidly because of the increasing interest and usage of these alloys as a result of:

1. Wartime welding experience gained in this field.
2. The unusual low-temperature physical properties of these alloys.
3. The continued improvement of coated electrodes for the metallic-arc welding of these alloys.

Like the iron-base metals and alloys copper alloys range in properties from very soft, ductile, pure copper to the hard, high strength, heat-treatable alloys, such as the aluminum bronzes and beryllium copper.

Almost all of these alloys are weldable by means of arc welding using either the metallic- or carbon-arc methods. Some few of the alloys are not weldable, such as the leaded bronzes.

Bronze electrodes are used extensively for repair weld-brazing cast irons and for depositing overlays for bearing, wear- and corrosion-resistant surfaces. However, with the increased demand for copper-alloy weldments in the chemical processing equipment field, the arc-welding process of joining these alloys is becoming more generally used in production fabrication because this method provides maximum welding speeds and weld quality with a minimum of skill required by the operator.

Since it is impossible to cover the entire field of copper alloy welding, the following most commonly used base metal groups have been selected for discussion:

Copper
Copper-Tin Alloys
Copper-Silicon Alloys
Copper-Zinc Alloys
Copper-Aluminum-Iron Alloys

Copper-Base Alloy Types and Properties

In order to develop more fully the values of welding and the weldability of copper and the copper-base alloys, it seems appropriate to discuss briefly alloy compositions and base metal physical properties.

Pure copper, like pure iron, is inherently a very soft, ductile metal of low tensile strength. Also, like iron, other elements must be alloyed with copper in order to induce higher strengths and hardnesses. In fact, some of the same hardeners are used for alloying with copper as those used with iron, namely: nickel, manganese and silicon.

Carbon, the primary hardener for steel, is never used in copper-base alloys because it does not alloy with copper. Actually, carbon is used as a cover for some copper-alloy melts to protect the molten metal from oxidation during the melting operation.

The primary hardening elements for the copper alloys are generally tin, silicon, zinc, aluminum and beryllium. For hardening effect, generally 1% of aluminum is equivalent to 6% of zinc; 3.5% of tin or 3.3% of iron.

The chemical compositions of the alloys selected are listed in Table 1. Two types of copper are listed—electrolytic and deoxidized. The differences between the two are differences in the impurities present.

In the copper-tin group, only the phosphor bronzes of tin content up to and including 10% will be discussed since these compositions are those most frequently welded.

In the copper-silicon group, discussion will be confined to those alloys most commonly used in welded, fabricated assemblies having a silicon content of around 3% with small amounts of iron, manganese and zinc present.

The most interesting alloys in the copper-zinc group to the welding engineer are the high zinc alloys with zinc contents between 37 and 43%, to which are added small amounts of iron, manganese, nickel and possibly tin.

Although there are many grades of aluminum bronzes, discussion will be confined to those alloys containing relatively high percentages of aluminum with iron as the secondary hardener.

Table 2 gives the average tensile strength and ductility as measured by elongation in 2 in. for copper and the copper alloys. Note the values are given as-cast, and wrought forms in both the soft and hard conditions. The as-cast, tensile strengths run from a low of 30,000 psi. for electrolytic, tough-pitch copper to a high of around 125,000 psi. for aluminum bronze.

Welding Recommendations

The copper-base alloys can be joined by any of the accepted welding methods. However, this paper is limited to those

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Table 1—Copper-Base Alloys—Composition

Alloying Elements—Copper Remainder

	Al	Sn	Zn	Si	Fe	Mn	P	O	Ni
Copper, electrolytic	....	....	.....	.....	...	...	.....	0.01–0.08*	....
Copper, deoxidized	....	....	.....	0–0.10	...	...	0–0.05	.....	....
Copper-tin	....	1–10.0	.....	.....	...	...	0.02–0.45	.....	....
Copper-silicon	....	0–2.0	0–5.0	0.25–5.0	0–2.5	0–1.5	.....	.....	....
Copper-zinc	....	0–1.5	37.0–43.0	.....	0–1.5	0–2.0	.....	.....	0–13.0
Copper-aluminum	1–14.5	0–2	.....	.....	0–4.5	0–1.0	.....	.....	0–5.0

* As cuprous oxide, Cu 99.9% min.

Table 2—Copper-Base Alloys—Physical Properties

Alloy Type	Average Tensile Strength, Psi. Cast	Wrought Soft	Wrought Hard	Elongation in 2 In., %, Soft	Heat Treatable
Copper, electrolytic, tough pitch	30,000	33,000	55,000	50	No
Copper, deoxidized	32,000	35,000	59,000	40	No
Copper-tin alloys Phosphor bronze	38,000– 45,000	45,000–55,000	75,000–105,000	65–45	No
Copper-silicon alloys Silicon bronze	40,000– 55,000	40,000–60,000	80,000–110,000	75–20	Some grades, Yes
Copper-zinc alloys Naval Brass, manganese bronze, Muntz metal	60,000–110,000	50,000–65,000	70,000–120,000	50–25	No
Copper-aluminum-iron Aluminum bronze	70,000–120,000	60,000–85,000	80,000–125,000	45– 5	Yes

primarily of arc welding for the alloys selected.

Techniques for the arc welding of copper and copper alloys do vary some from those used in steel welding because of:

1. Higher thermal conductivity.
2. Electrical conductivity.
3. Higher coefficients of thermal expansion.
4. Lower melting points.
5. The greater fluidity of the molten metal at arc welding temperatures.

Therefore, it is necessary generally in copper-alloy welding to:

1. Allow more space in the joint for expansion.
2. Tack more frequently.
3. Use higher preheats.
4. Use higher amperage for size of electrode and plate thickness.
5. Travel at a faster rate of speed than is used in mild steel welding.

Joint designs are varied accordingly from standard mild steel practice in that wider grooves are used and sharp corners must be avoided.

Recommended joint designs for copper and copper alloys are shown in Fig. 1. Tight joints are to be avoided in welding light-gage copper-base alloys as shown in Example 1. The first two joints are those most frequently used for light sections from 1/32 to 1/8 in. in thickness with the metallic-arc and carbon-arc methods. Lap joints on very thin sections are usually silver brazed.

For plate thicknesses of 5/32 to 7/16 in. a 90° single V groove is recommended with a backup strip of copper or matching alloy as shown in Example 4.

For heavier plate thicknesses of 3/4 in. and above, three typical groove designs are given in Examples 5, 6 and 7. The groove widths are generally greater than those used in mild steel welding. For example, the single V groove, No. 5, is 90° overall as compared to similar mild steel grooves that are usually 45 or 60° overall. The U grooves given in Examples 6 and 7 have an opening at the top of 30 to 40° with a 1/4 in. radius at the bottom as compared to a 20° opening for similar grooves in mild steel.

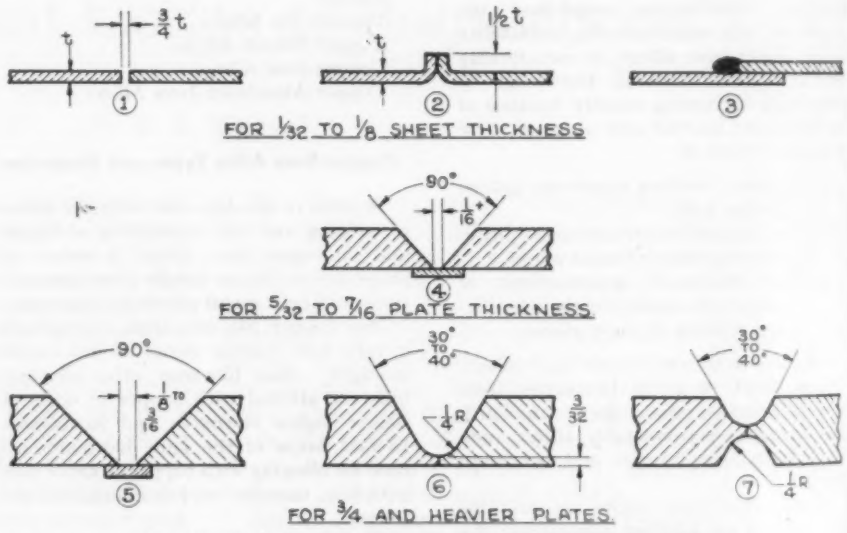

Fig. 1—Recommended Joint Designs for Copper-Base Alloys

Table 3—Copper and Copper-Alloy Electrode Classification

(Metallic-arc and Carbon-arc)

Core Wire Type	Proposed A.W.S.-A.S.T.M. Designation	Deposit Composition, % (Plus Copper)		Form Available	Base Metals Welded
Copper, deoxidized	E Cu	Copper	99.0	Coated and bare	Copper
Phosphor bronze	E Cu Sn-A	Tin	4.0– 6.0	Coated and bare	Copper, brass, tin Bronzes, iron-base metals
		Phosphorus	0.3 max.		
	E Cu Sn-C	Tin	7.0– 9.0	Coated and bare	Brass, tin bronzes Iron-base metals
		Phosphorus	0.3 max.		
Silicon bronze	E Cu Si	Silicon	2.5– 3.75	Coated and bare	Silicon bronzes
		Copper	94.0 min.		
Aluminum bronzes	E Cu Al-A	Aluminum	7.5– 9.0	Coated	Aluminum bronzes, brass, silicon bronzes, iron-base metals
		Iron	1.5 max.		
	E Cu Al-B	Aluminum	9.0–10.0	Coated	Aluminum bronzes and overlays
		Iron	3.0– 5.0		
	E Cu Al-C	Aluminum	10.0–11.0	Coated	Aluminum bronzes and overlays
		Iron	3.0– 5.0		
	E Cu Al-D	Aluminum	11.0–12.0	Coated	Aluminum bronzes and overlays
		Iron	3.0– 5.0		
	E Cu Al-E	Aluminum	12.0–13.0	Coated	Aluminum bronzes and overlays
		Iron	3.0– 5.0		

Table 4—Copper

	Physical Properties —Ultimate Tensile Strength, Psi., Av.— Cast	Wrought (Soft)	Weld Metal	Elongation in 2 In., % Wrought (Soft)	Weld Metal
Copper, deoxidized	32,000	35,000	25,000	40	20
Copper, electrolytic	30,000	33,000	....	50	..

Welding Methods

	Welding Process	Electrodes and Rods	Form	Preheat
Copper, deoxidized	Metallic-arc	E Cu	Coated	
		Phos-copper	Bare	
		E Cu Sn-A	Coated or bare	800–1000° F.
Copper, deoxidized	Carbon-arc	E Cu	Bare	
		Phos-copper	Bare	
		E Cu Sn-A	Bare	800–1000° F.
Copper, electrolytic	Brazing (gas)	Silver solder	Bare	500° F.
	Brazing (gas)	Phos-copper	Bare	800–1000° F.
	Metallic-arc	E Cu Sn A	Coated or bare	800–1000° F.

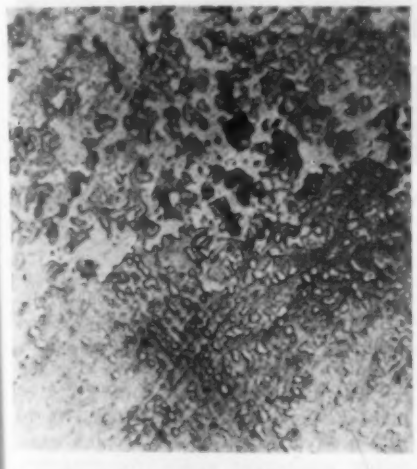

Fig. 2—Structure Fusion Zone Between 5% Tin Phosphor Bronze Deposit and Phosphor Bronze Grade A Plate

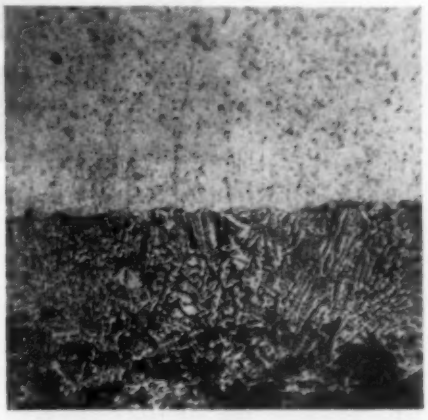

Fig. 3—Weld-Brazed Bond Between 5% Tin Phosphor Bronze Deposit (Top) and Cast Iron

These wider grooves are necessary in welding copper-base alloys in order to eliminate under-cutting of the side walls and resultant slag entrapments and porosity at the fusion zone, due, of course, to the lower melting points of the copper-base alloys.

If these few simple rules are followed in designing arc-welded joints for the copper alloys, many difficulties can be avoided in the welding operations.

Copper and Copper-Alloy Electrodes

Welding electrodes for use in welding copper and copper alloys are similar in composition to the wrought metals discussed previously, Table 3. Minor changes are, however, necessary in some cases in order to:

1. Improve welding characteristics.
2. Control deposit physical properties.
3. Compensate for losses of alloys in the remelting process.

The oxides of copper, tin, aluminum and the many other alloying metals are difficult to remove from the weld metal during the short time involved in transferring the metal across the arc. Therefore the necessity to use very strong fluxes such as fluorides in the coatings of metallic-arc welding electrodes, and the powdered fluxes for oxyacetylene welding. In this respect the copper-base alloy coatings and fluxes are very similar to those used in stainless steel welding. The same safety precautions must be followed in ventilating welding booths and closed vessels.

From Table 3, it can be seen that all of the previously listed base metals are used for electrode core wires and rods, except the brasses. Brass rods are never used in this manner for electric welding because the zinc present volatilizes in the arc producing very porous deposits. Brass rods are, however, used for brazing with the oxyacetylene torch.

Also, lead bearing copper-base alloys are never used as weldrod in carbon-arc welding or core wires in coated electrodes because lead, like zinc, volatilizes readily upon remelting, due to its low melting point. Lead does not alloy with copper, but when present is a mechanical mixture unevenly distributed throughout the alloy.

Taking one alloy group at a time, an endeavor will be made to give as briefly as possible:

1. A description of the metal or alloy.
2. The type of weldrod or electrode recommended for use in welding.
3. Some fundamental arc-welding characteristics and recommendations.

Copper

Two types of copper are given in Table 4. One form is known as electrolytic, tough-pitch copper and the other is deoxidized copper.

Electrolytic, tough-pitch copper is not recommended for joining by means of

Table 5—Copper-Tin Alloys

	Physical Properties —Ultimate Tensile Strength, Psi., Av.— Cast	Wrought (Soft)	Weld Metal	Elongation in 2 In., % Wrought (Soft)	Weld Metal	Hardness Brinell (500 Kg.), Weld Metal
Alloy						
Phosphor bronze (Grade A)	38,000	45,000	40,000	45	15–40*	70– 80
Phosphor bronze (Grade C)	42,000	55,000	45,000	55	12	80–100
Phosphor bronze (Grade D)	45,000	60,000	50,000	60	10	90–110

Welding Methods

	Welding Process	Electrodes and Rods	Form	Preheat
Phosphor bronze (Grade A)	Metallic- or carbon-arc	E Cu Sn-A	Coated	300–400° F.
			Bare	
Phosphor bronze (Grade C)	Metallic- or carbon-arc	E Cu Sn-C	Coated	300–400° F.
			Bare	
Phosphor bronze (Grade D)	Metallic- or carbon-arc	E Cu Sn-C	Coated	400–600° F.
		Phosphor bronze D	Bare	

* Developed by hot peening.

welding, if strength welds are desired, because the dispersed cuprous oxides present in the metal upon welding cause embrittlement of the joint at the fusion zone, resulting in loss of strength to approximately one-third that of the base metal. Wherever possible, strength joints should be made in this metal by soft soldering, silver or phos-copper brazing. If strength joints are not essential, welding can be readily accomplished with coated phosphor bronze electrodes using the metallic-arc method.

Deoxidized copper is recommended for use in equipment that is to be fabricated by welding. This form of copper may be deoxidized with either phosphorus or silicon. It is not subject to oxide embrittlement, and therefore can be satisfactorily welded by means of the metallic- or carbon-arc methods. Silicon deoxidized copper is, however, preferred since it has greater hot ductility than the phosphorous deoxidized type.

The carbon-arc method of welding copper is preferred using a bare silicon deoxidized copper filler rod. However, if corrosion-resistance is not a service factor, 4–5% tin phosphor bronze and silicon bronze bare rods can be used with excellent results. Usually the phosphor bronze rod will be selected because of color match.

In the metallic-arc welding of deoxidized copper, the most common coated electrode used in the 5% tin phosphor bronze type, because the deposit produced more nearly approaches that of copper in physical properties and color. Also, coated aluminum bronze and silicon bronze electrodes have been used satisfactorily where corrosion is not a factor to be considered.

For welding with either the carbon- or metallic-arc methods, high preheats and interpass temperatures of around 800 to 1000° F. must be used and maintained, especially on heavy sections due to the high thermal conductivity of copper.

Copper flows sluggishly in the molten state. Preheating aids in flowing the weld metal more uniformly into the side walls of the groove.

In metallic-arc welding, the largest diameter electrode possible should be selected and high amperage is required to flow the weld metal properly in order to avoid under-cutting and the resultant slag inclusions.

Welded joints in copper should not be restrained by clamping or cracks will develop in the deposit.

Phosphor Bronzes

The most commonly known alloys in the copper-tin group are the phosphor bronzes, Table 5. Phosphorus is used as a deoxidizer, therefore the name phosphor bronze. Other alloys in this group are gun metal, bell metal and bearing bronze. However, this discussion will be confined to the welding of the phosphor bronzes of low tin content.

The tin bronzes are used extensively for structural shapes where good corrosion resistance is required; for steam fittings; for bearings operating at low speeds; and for worm gears.

These alloys are subject to internal shrinkage, and cracking may occur if parts made from these alloys subjected to heavy loads are not properly designed. These alloys have a tree-needlelike dendritic structure in castings which tends to leave voids between the copper-tin crystals. However, this inherent, inter-dendritic unsoundness in castings that are to be subjected to hydrostatic pressure can be corrected by good foundry technique, annealing and lead additions to the alloy. Lead may also be added to the alloy to improve machinability.

In the past, the phosphor bronzes have required very little welding except in maintenance and repair work. However, recently phosphor bronze Grade A rolled plate is beginning to come into use in the pressure vessel, food and chemical processing equipment fields requiring fabrication by means of welding.

The tin bronzes are inclined to be hot

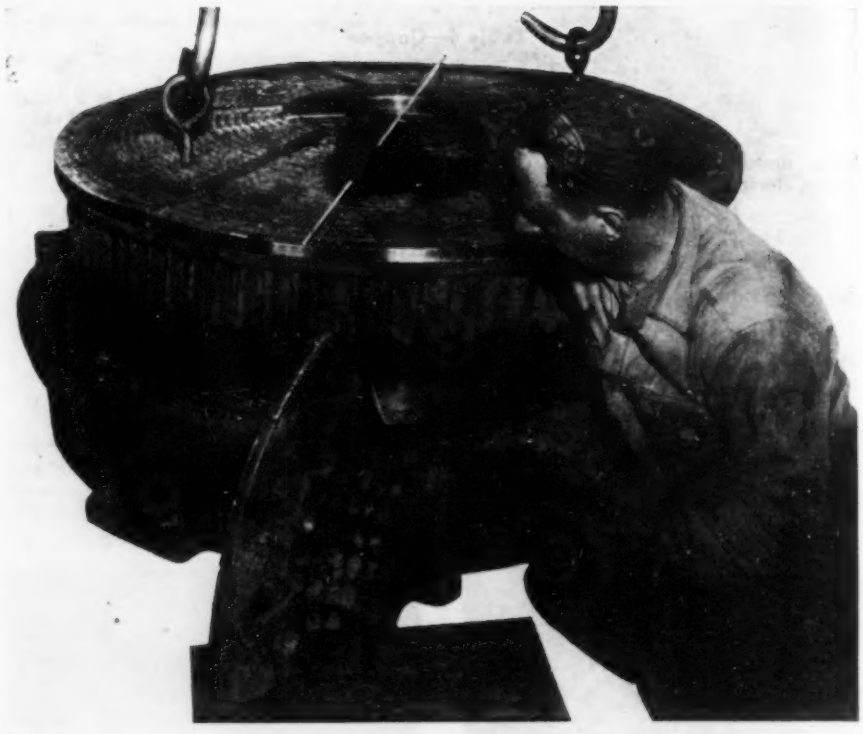

Fig. 4—Rebuilt Grain Drying Press Disk with 5% Tin Phosphor Bronze Deposit

Fig. 5—Phosphor Bronze Spacer Ring Welded Vertically with 5% Tin, Phosphor Bronze Electrode

Table 6—Copper-Silicon Alloys

Physical Properties

Alloy	Ultimate Tensile Strength, Psi., Av. Cast	Wrought (Soft)	Weld Metal	Elongation in 2 In., % Soft	Weld Metal	Hardness, Brinell (500 Kg.), Weld Metal
Silicon bronzes	40,000–50,000	40,000–60,000	40,000–45,000	75.0–20.0	20	80–100

Welding Methods

	Welding Process	Electrodes and Rods	Form	Preheat
Silicon bronzes	Carbon-arc	E Cu Si	Bare	60–212° F.
	Metallic-arc	E Cu Al-A	Coated	60–212° F.
		E Cu Si	Coated	

short and subject to inter-dendritic shrinkage of the low melting constituents requiring rapid welding. Therefore the metallic-arc method is the most satisfactory means of joining these alloys.

The 5, 8 and occasionally the 10% tin content phosphor bronze rods are used in the coated or bare forms for the metallic-arc welding of copper, brass, bronze, and alloys of iron, such as cast and malleable iron, high manganese steels, and other alloys that are difficult to weld with ferrous electrodes.

The phosphor bronzes have the tendency to flow sluggishly, requiring preheats and interpass temperatures of around 400° F. In the low tin compositions, wide grooves are also recommended with higher amperage in order to wash the side walls properly.

Either stringer or weave beads may be used. However, if maximum strength and ductility are required in the joint, the physical properties of the weld metal can be greatly improved by a post-heat treatment at 900° F. and hot peening of the deposit. In either case, the coarse dendritic grain structure obtained as welded is refined, resulting in increased strength and ductility. It should be observed that as the tin content of the cast wrought plates and weld deposits increase the ultimate tensile strength increases.

The tensile strengths of the metallic-arc welded joints compare favorably with those of the cast and soft wrought plates.

Figure 2 shows the structure of a typical 5% tin phosphor bronze electrode deposit as welded with the metallic-arc. This is a single phase alloy, and the crystals are rather large due to rapid cooling.

Phosphor bronze electrodes are used extensively for repair welding of cast iron. Figure 3 shows the fusion zone between a 5% tin, phosphor bronze electrode deposit and cast iron. Note the typical weld-brazed bond obtained.

The carbon-arc method is also satisfactory for welding the tin bronzes using a bare phosphor bronze rod. Like the metallic-arc method, the heat is more concentrated and contraction strains are reduced to a minimum The arc should be directed onto the weldrod and not against the base plate.

Figure 4 is a typical overlay application using phosphor bronze electrodes and shows the rebuilt disk segments on a pulp and grain drying press used in breweries, distilleries, malt processing plants and citrus industries for extracting juices and drying grain and citrus pulp. Phorphor bronze was used for this particular overlay for wear- and corrosion-resistant qualities. The base metal is a phosphor bronze Grade A casting.

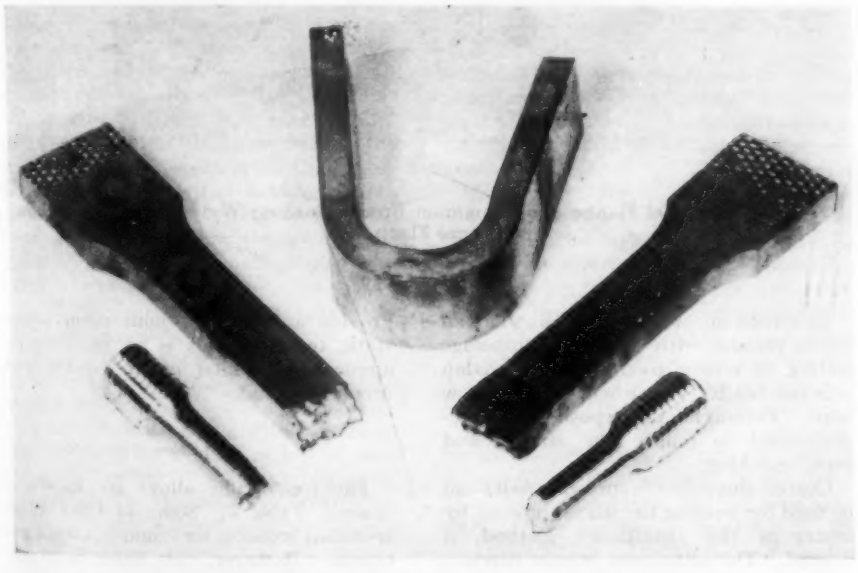

Fig. 6—Test Specimens—Aluminum Bronze Deposit—Silicon Bronze Base Metal

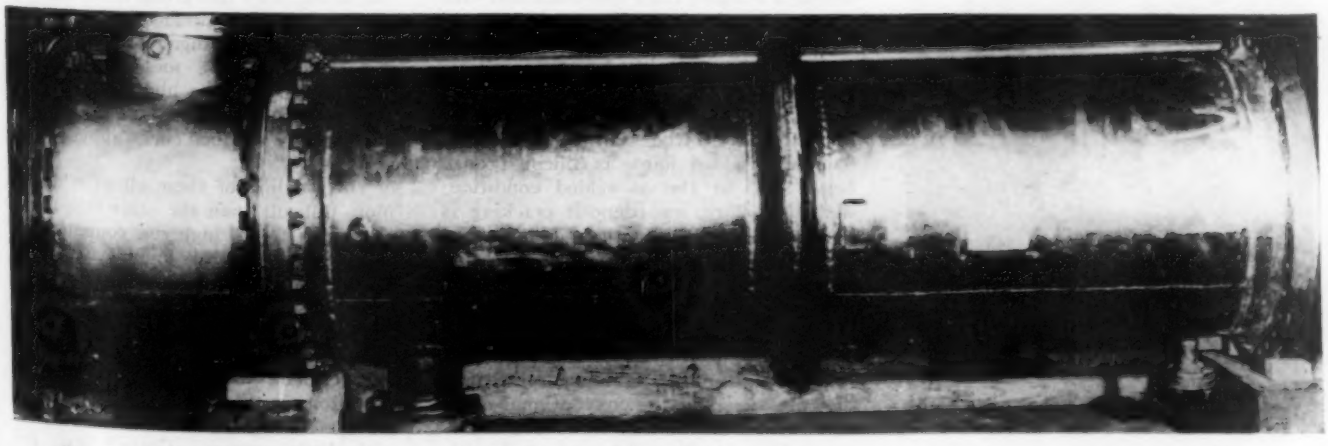

Fig. 7—Silicon Bronze Condenser Tube Sheets Welded to Mild Steel Shell Using Aluminum Bronze Electrodes

Figure 5 shows a vertical groove weld in phosphor bronze plate. This bronze wear or spacer ring is used between the wheel hub and driving box on a locomotive. The spacer ring is split so that it can be place over the axle, and then welded into place.

Silicon Bronzes

The silicon bronzes, such as Olympic, Herculoy, Duronze and Everdur, are alloys of copper and silicon, Table 6. Silicon is the primary hardener along with such secondary hardeners as manganese, iron and zinc. Ultimate tensile strengths and ductility are approximately the same as those of the tin bronzes.

These alloys have excellent physical properties in the wrought or rolled form, combining high strength with good ductility. The higher strengths are usually developed through additions of alloys other than silicon and through heat treatment.

The silicon bronzes are probably the most widely used of the copper-base alloys at the present time for fabricating chemical processing equipment, sewage disposal equipment and similar weldments by arc-welding methods.

Welding is facilitated by the low heat conductivity of these alloys. Silicon bronzes are, however, extremely hot short.

Because the silicon bronzes have a lower thermal conductivity than the other copper-base alloys, more nearly approaching that of steel, groove preparations are similar to those used in mild steel welding.

The carbon-arc method is usually recommended with bare silicon bronze rods for groove welding in heavy sections because excessive deposit cracking was usually encountered in the past when metallic-arc welding with coated silicon bronze electrodes. However, recent developments in the coated electrode field seem to indicate that entirely satisfactory, crack-free welds can now be made consistently with coated silicon bronze electrodes.

Rapid welding is required in welding the silicon bronzes because the alloys are hot short. Preheating should not be used in welding these alloys.

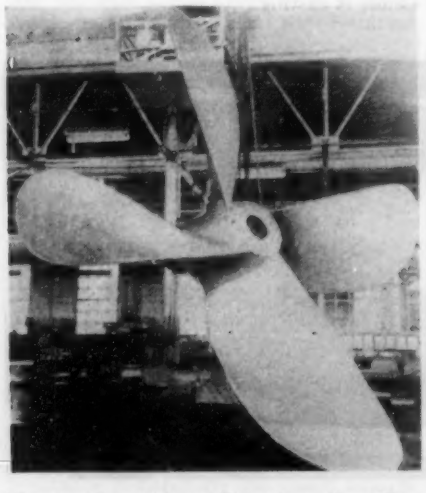

Fig. 8—Naval Brass Ship Propeller, Keyway Repair Welded with Phosphor Bronze Electrodes

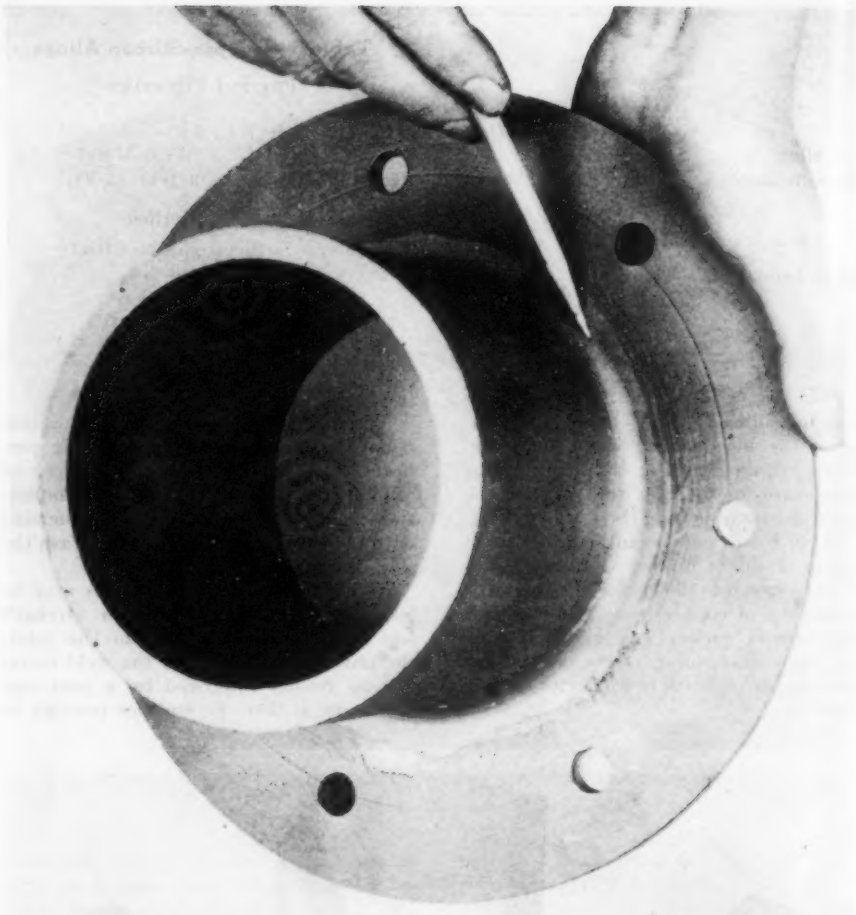

Fig. 9—Mild Steel Flange and Aluminum Bronze Bushing Welded with Aluminum Bronze Electrodes

In carbon-arc welding, hold as short an arc as possible with the lowest amperage setting to secure good fusion. Overlap previous beads $^1/_2$ in. when starting a new bead. Peening of the deposit is also recommended to relieve the stresses and avoid cracking.

Coated aluminum bronze electrodes can be used for welding the silicon bronzes by means of the metallic-arc method, if desired. The aluminum bronze deposits are not hot short, and therefore eliminate deposit cracking. The deposit tensile strength is higher than those obtained with silicon bronze electrodes. This type of electrode is also used extensively for welding silicon bronze to steel.

Typical weld test specimens made from plates of silicon bronze welded with aluminum bronze electrodes are shown in Fig. 6. Such welded joints in silicon bronze bend 180° in the as-welded condition, without failure, and deposit cracking is not encountered during the welding operations.

A typical example of the use of silicon bronze in industry is the condenser shown in Fig. 7. The shell is made of mild steel and the tubes and tube sheets are made of silicon bronze. The tubes are rolled into the tube sheets in the conventional manner. However, the tube sheet is metallic-arc welded to the mild steel shell with aluminum bronze electrodes to avoid excessive weld cracking in fabrication, and provide a leak-proof joint upon hydrostatic testing. This is an excellent example of dissimilar metal welding with bronze electrodes.

Brasses

The copper-zinc alloys are known as brasses, Table 7. Some of these alloys are called bronzes; for example, manganese bronze. However, this name is a misnomer.

Only the very high zinc brasses will be discussed, since this group is the one most widely used and welded. Typical high zinc brasses are manganese bronze, Naval Brass and Muntz metal.

These alloys have high strength, good ductility and good corrosion resistance as cast. They are good cheap alloys for general use.

The welding of these alloys is a little more difficult than the other copper-base alloys due to the high zinc content. The zinc volatilizes readily upon heating to the welding temperatures.

Due to the high zinc content, and the low melting points of the brasses, these alloys are limited in use as brazing rods for oxyacetylene welding. Some work has been done in the past to develop a coated electrode using brass as a core wire, but with little success. Coated brass rod deposits are very porous due to the zinc volatilization. The bare wires are used

Table 7—Copper-Zinc Alloys

Physical Properties

Alloy	Ultimate Tensile Strength, Psi., Av. Cast	Ultimate Tensile Strength, Psi., Av. Wrought (Soft)	Ultimate Tensile Strength, Psi., Av. Weld Metal	Elongation in 2 In., % Wrought (Soft)	Elongation in 2 In., % Weld Metal
Brass	60,000–110,000	50,000–65,000	30,000–70,000	50–25	5–20

Welding Methods

	Welding Process	Electrodes and Rods	Form	Preheat
Brass (low strength)	Metallic- or Carbon-arc	E Cu Sn-A or E Cu Sn-C	Coated or bare	400–800° F.
Brass (medium and high strength)	Metallic- or Carbon-arc	E Cu Al-A	Coated	400–800° F.

extensively for the brazing of all metals having a higher melting point than the brasses.

For the metallic-arc welding of the brasses, two coated electrodes are recommended for use—the 5% tin phosphor bronze and the aluminum bronze electrodes.

The phosphor bronze electrode is used for welding the low strength alloys, such as Naval Brass. The deposit physical properties are comparable to those of the brass base metal.

For welding the higher strength brasses like manganese bronze, the only electrodes that will produce comparable physical properties are the aluminum bronzes. The aluminum bronzes also provide an excellent color match.

Although relatively high preheats are essential (400 to 800° F.) in arc welding the brasses, they are usually lower than those required in oxyacetylene welding. High amperage must also be used in welding the brasses in order to flow the weld metal uniformly into the side walls of the wide grooves recommended.

In Table 7 excellent average, all-weld metal physical properties, obtained from aluminum bronze electrode deposits in manganese bronze base plates by the metallic-arc method, will be observed.

In metallic-arc welding with aluminum bronze electrodes, a small puddle of weld metal must be started at one point playing the arc on the deposit and progressing slowly. In this manner, a brazing action is obtained, and the zinc losses are held to a minimum. This special technique is not required when welding the low strength brasses with a phosphor bronze electrode.

A good example of brass welding is illustrated in Fig. 8. This shows a large Naval Brass ship propeller. The keyway was worn excessively, and had to be repaired. Phosphor bronze electrodes were used to weld the worn keyway, and another one was cut on the opposite side of the propeller.

Aluminum Bronze

The aluminum bronzes, such as Ampco Metal, are alloys of copper, aluminum and iron, Table 8. Some compositions have additions of nickel, manganese and occasionally tin.

Aluminum bronze electrodes, in the low aluminum grades, are the best qualified of all the high strength bronzes for many diversified welding applications because the deposits are not hot short. That is, they have exceptionally good hot strength and hot ductility. The alloys are dense and do not contain elements that volatilize in the arc causing porosity and loss of strength in the welded joints.

The aluminum bronzes are analogous in the copper-base alloy field to the low-alloy, high-tensile strength steels developed for weldability in the iron-base alloy field. They are also comparable in the copper-base field to the stainless steels in corrosion resistant values.

Aluminum bronze electrodes are supplied in the coated form only for metallic- and carbon-arc welding. These electrodes are even more versatile in recommended uses than the phosphor bronze electrodes, since they produce deposits of much higher values with regard to tensile strength, yield, hardness, wear- and corrosion-resistance—and the deposits are not hot short.

Five grades of aluminum bronze electrodes are available, varying in aluminum and iron content and deposit hardness for welding aluminum bronzes from 120 to 300 Brinell.

In addition to their use in joining the various grades of aluminum bronzes, the softer grades are used for joining dissimilar metals, ferrous-, nickel- and other copper-base alloys.

It should be observed in Table 8 that all-weld metal physical properties are equivalent to those of similar grades of aluminum bronze base metals.

An ideal example of dissimilar metal welding with aluminum bronze electrodes is the flanged bushing, Fig. 9, fabricated from aluminum bronze and mild steel.

A typical aluminum bronze joining application is the Venturi tubes illustrated in Fig. 10 and fabricated from plate and centrifugal castings using the carbon-arc process.

Groove welding technique is similar to that used in steel welding. A preheat of

Table 8—Copper-Aluminum-Iron Alloys

Physical Properties

Alloy	Ultimate Tensile Strength, Psi., Av. Cast	Ultimate Tensile Strength, Psi., Av. Wrought (Soft)	Ultimate Tensile Strength, Psi., Av. Weld Metal	Elongation in 2 In., % Wrought (Soft)	Elongation in 2 In., % Weld Metal
Aluminum bronzes	70,000–120,000	60,000–85,000	70,000–90,000	45–5	25–0.5

Welding Methods

Aluminum Bronze Grade	Chemical Composition (Plus Copper)		Welding Process	Electrodes and Rods*	Preheat
1	Al	5.0 –10.0	Metallic or	E Cu Al-A	250– 350° F.
	Fe	0 – 3.25	Carbon-arc		
2	Al	9.6 –11.0	Same	E Cu Al-B	250– 450° F.
	Fe	3.0 – 4.25			
3	Al	11.4 –12.2	Same	E Cu Al-C	250– 450° F.
	Fe	3.25– 4.5			
4	Al	12.6 –13.4	Same	E Cu Al-D	800–1000° F.
	Fe	3.5 – 5.0			
5	Al	13.7 –14.4	Same	E Cu Al-E	800–1000° F.
	Fe	4.0 – 5.25			

* Coated only.

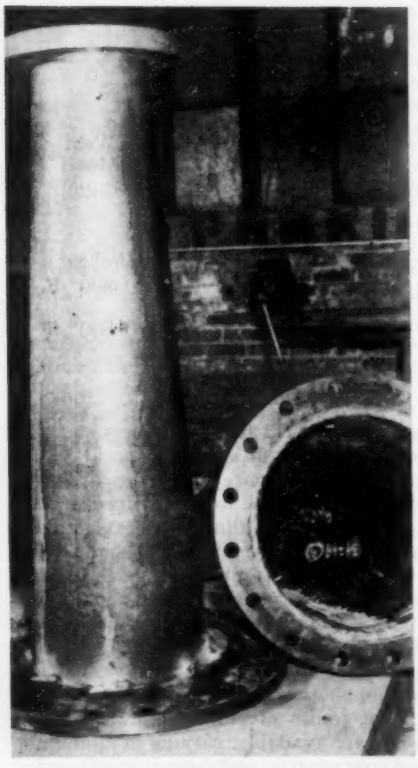

Fig. 10—Venturi Tubes Fabricated from Aluminum Bronze Rolled Plate and Centrifugal Castings

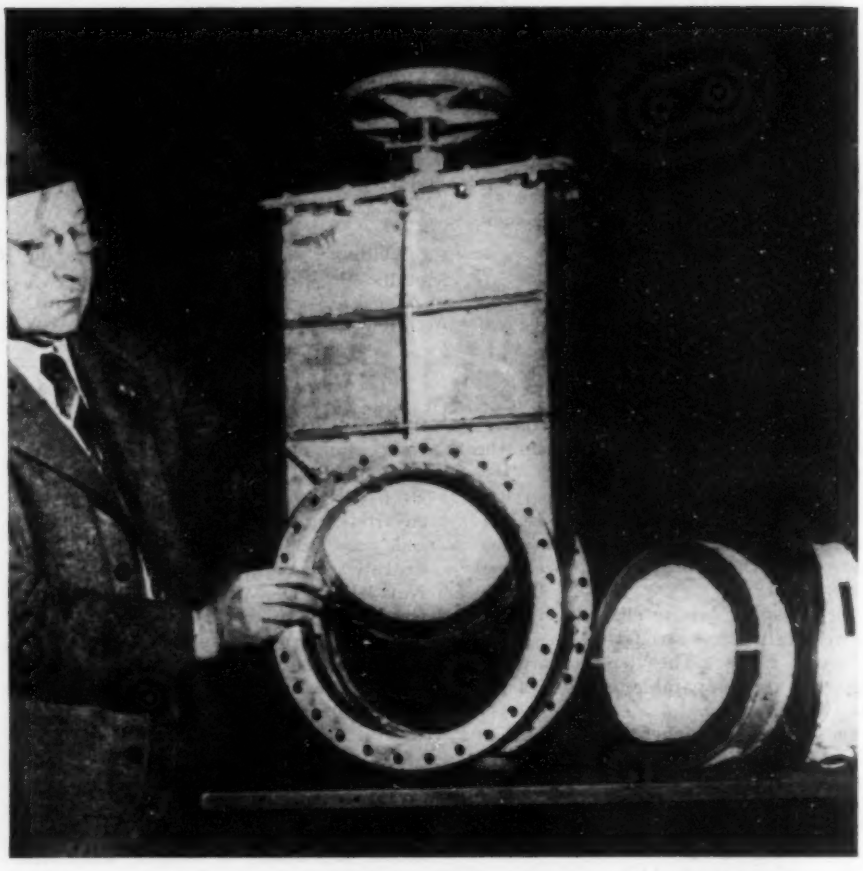

Fig. 11—Navy Ventilator Valve Seats and Faces Overlayed with Aluminum Bronze

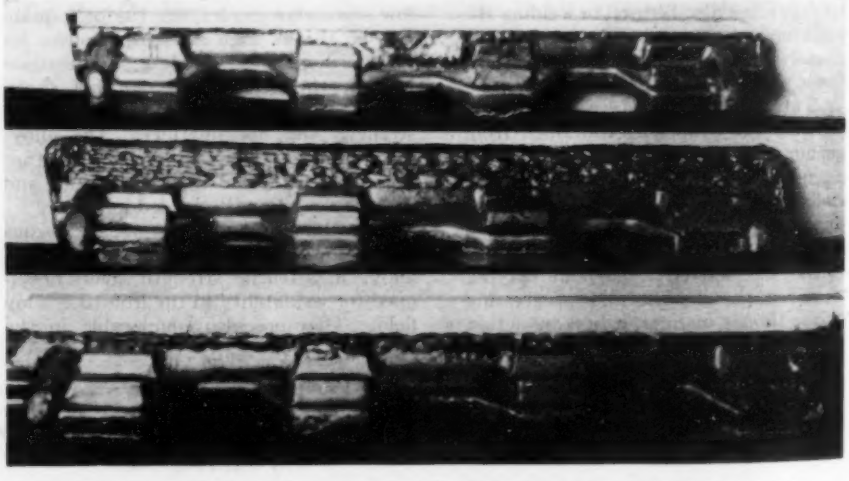

Fig. 12—Pipe Mill Arbor Shoe Overlayed with Aluminum Bronze for Wear Resistance —As Worn (Top), Welded (Center), Machined (Bottom)

200 to 300° F. is essential in welding heavy sections. Unlike most other copper-base alloys, either weave or stringer beads may be used with equal success in metallic-arc welding. Also bead thickness seems to have little effect upon the resultant deposit physical properties.

For carbon-arc welding, the technique is also similar to that used in joining other alloys or metals except for the use of a coated filler rod which is necessary in aluminum bronze welding.

All five grades of aluminum bronze electrodes are used for bearing surface overlays. For such applications, the electrode is selected having a deposit hardness 50 to 75 points Brinell lower than the mating material. Many of these electrodes are used for wear- and corrosion-resistant overlays.

For example, the Navy ventilator valve body, Fig. 11, was fabricated from $^1/_8$- to $^5/_{16}$-in. mild steel plate and galvanized to resist salt water corrosion. The valve faces and seats were, however, overlayed with aluminum bronze weld deposit to resist wear, erosion and salt water corrosion.

A typical wear-resisting overlay application is the arbor shoe, Fig. 12, used in a large pipe mill. Aluminum bronze and aluminum bronze welded overlays for repair and maintenance prove satisfactory because of excellent wear-resistance in metal to metal contact, the high strength of the alloy and the fact that the alloy will not score or mark the finished product.

Generally, bronze electrodes are used to overlay carbon steel and cast iron surfaces although in many instances worn copper-base alloy wear surfaces are repair welded. In overlaying iron-base metals, the use of a wide, fast weave technique at medium amperage is recommended in order to minimize base metal dilution in applying the initial layer. For successive layers, the amperage may be increased for more rapid deposition with the weave bead technique. Where perfectly dense deposits are required in die welding, the carbon-arc method of deposition is preferred to the metallic-arc method.

Summary

Within recent years as the result of wartime usage, research and development work in copper-base alloy welding and electrodes has assumed increasing importance to industry in general and greatly expanded the use of peacetime arc welding in this field.

Where prewar usage of copper-base alloy electrodes was primarily for maintenance and repair, it is now becoming apparent that production fabrication and overlay applications are rapidly increasing as industry becomes more familiar with the alloys.

The arc welding of copper-base alloys presents few difficulties that cannot be overcome through having an adequate

knowledge of the composition of the metal or alloy to be welded, its inherent metallurgical characteristics together with proper joint preparation, preheat and welding technique required for the specific base metal composition.

The copper-base alloys have lower melting points, higher thermal conductivities, higher coefficients of thermal expansion and the molten metal is more fluid than the iron-base alloys at arc-welding temperatures.

Therefore, generally, wider grooves and root spacings are used together with a faster rate of travel. Also, with the exception of brass, as the alloy becomes more rich in copper, higher amperage and preheats are required for increasing plate thickness.

Although the information contained in this paper regarding the arc welding of copper and copper-base alloys is far from complete in view of the large number of alloys available, it has provided some basic, fundamental principles involved and deposit physical property data that may be helpful in stimulating additional research and development efforts in this field of welding.

The Maintenance Weldery*

By Cleo E. Hook†

Introduction

I ONCE heard the owner of a job shop say that it would take $20,000 worth of equipment to handle the types of work he could get to do, and if he had the $20,000 to invest in a shop, he wouldn't need the shop—he'd have enough money without it.

Undoubtedly, a lot of manufacturers feel the same way about equipping the maintenance weldery, for while it requires only a small fraction of the $20,000 the fellow in the story needed, the outlay for materials, equipment, floor space, etc., is somewhat greater than that required for certain other types of work, such as carpentery, plumbing, sheet metal maintenance, etc. However, the vast variety of services rendered by the maintenance weldery, when properly staffed and tied in with process engineering, tooling, efficiency and actual production work, far more than compensates for the actual outlay in financing and operating the maintenance weldery.

While I have based the contents of this paper on actual experience and observation in maintenance and maintenance welding problems, for several years operating a maintenance weldery (though it held no such dignified title), I do not wish to mislead anyone into thinking that we now have such a shop actually set up and operating as is set out in this paper. While I have actually experienced everything mentioned in this paper at some time or other in the last thirteen years, there is no plant to my knowledge in which such a setup is maintained in exactly the manner described herein. Also for the mutual protection of both my employers and myself, we want it understood that those things stated herein are not necessarily the opinions of my company nor hold their official sanction, though they were glad that one of their men should be accorded the honor of speaking to you on this subject this afternoon.

History

When we set up our first maintenance weldery, we had no such thing in mind as I speak of here. My boss, the efficiency engineer and I cleaned out the 20 ft. x 30 ft. brick room next to the boiler room of the old furniture factory in which our company had set up their Seymour muffler plant (where they at one time reached a maximum speed of 600 mufflers per hour on one line) and put in an ancient hundred-amp. d.-c. welding generator and a work bench on a dirt floor. In this room, where we gradually added equipment as we could salvage it from the junk pile (along with a good cutting and welding torch), we built conveyors, bins, chutes, tables, special trucks, all sorts of parts-handling equipment and gadgets to make production work easier and more efficient. Practically everything we built was made of materials discarded from the dismantled furniture factory equipment and the sheet steel used in regular production work. Two of us (myself and a helper) built whatever we needed along these lines (even to constructing an arc welder of salvage materials when a carbon arc job could not be kept running with the then conventional equipment).

In addition to the above services rendered to the plant, we also took care of the excessive number of breakdowns that usually occur when a new type of work is started with operating and supervisory personnel not entirely accustomed to that sort of thing. These breakdowns were fractured and crushed die inserts, broken punch press frames and cranks, galled wedge blocks, worn forming dies, and even a few broken flywheel spokes and bull gears. We became accustomed to "dental work" on large gears, building them up with low fuming bronze to approximate shape, and "running them through" while still almost red-hot. We developed a technique of punch press crankshaft welding by which we did not remove the shaft from the press, even for finish machining. While we had never heard of carbon arc cutting of cast iron, we developed a technique of preparing large castings for bronze welding at a speed and ease which to my knowledge has never been equaled by any other method. In short, we learned maintenance welding the hard way. Necessity was the mother of invention. We learned how to do things without elaborate expensive equipment, and the results we obtained more than justified the use of these methods. Many of these methods have been described in detail in a national welding magazine‡, and need not be taken up here.

* Scheduled for Twenty-eighth Annual Meeting, A.W.S., Chicago, Illinois, week of Oct. 19, 1947.

† Noblitt-Sparks Industries, Inc., Columbus, Indiana.

‡ "Bennie the Welder," *Industry & Welding*, 1938 to 1941.

Organizational Setup

The proper relationship of the maintenance weldery to the rest of the plant organization is very important if the weldery is to do its best work. The weldery should be supervised by a man of wide practical as well as theoretical background who works directly for the highest executive in the organization with the authority to "free lance" wherever he may see fit in his efforts to determine the best and most economical way to attain the results he hopes to accomplish. He should have the right to consult with the efficiency engineer, the process engineer, the tool-room or maintenance foreman, the big boss or the line operator with equal impunity. He should have the right to go into any section of the shop or office at any reasonable time without question. He must have available the cooperation (but not the authority) of every supervisory or engineering person in the entire organization. Petty jealousies and red tape *must not* enter into his relationships with those around him. He must have equally the right to say to the purchasing agent "Call this in rush" or to the straw boss who insists on riding his own hobby, "No, I'll have to do it this way" if the way is the one agreed on by those in charge. He must be a coordinator of ideas with the the right in the last analysis to do his job the cheapest way consistent with quality. He must be a practical engineer who first of all knows welding, then machine construction, production methods, tool-room practice, maintenance and installation methods, a man with a vivid imagination and the ability to temper that imagination with the limitations of sound judgement—"common sense." At all times he must remember that he is responsible to the "man up top side" and be certain he has the best solution under the circumstances for any problem before he starts construction or repair.

You may well say, "Where will we find such a man?" More than likely you already have some maintenance welder who can head such a weldery. He need not be a college graduate. A man with a thorough knowledge of physics and shop practice can acquire the rest if he is naturally adapted to job weldery and machine construction technique.

Equipment Setup

You probably also have the equipment for your maintenance weldery available somewhere around the shop. In a plant the size of the one I spoke of at the beginning there are usually several arc welders around that for some reason or other are out of production. Give an old arc-welding machine to a maintenance welder and even though it may have no meters and may lack a polarity switch, he will "fix it up" to his own satisfaction and have, in his estimation, the "best welder in the shop." I've seen it happen several times. A couple of welders, a 100- or 150-amp., and a 400-amp. d.-c. (with a little a.-c. transformer if 3-phase distribution over the plant is poor) will take care of the arc machine needs. A heavy-duty oxyacetylene portable torch outfit with cutting attachment and 50 feet of $^3/_{16}$-inch twin hose, and an airplane type small torch will take care of most needs, though if there is much cutting to do, a second portable outfit may be required. The rest of the equipment may consist of benches (one brick top and one $^1/_2$-in.- thick steel plate top), tool bench, two vises (one heavy-duty on steel bench for hot bending, etc.), a small 100- or 200-lb. positioner, 6-in. electric hand grinder with bench mount, two $^1/_2$-ton differential hoists with suitable overhead tram ways, cables, electrode holders, chains and hand tools. Sometimes a sort of a stock room for angle iron, pipe, and large steel bars and plates for the tool room is is kept within reach of the cutting hose.

It is usually advantageous to locate the tool room, the maintenance shop, and the maintenance weldery near each other in some central location in the shop. If a shed area is available for building objects too large for the room, as many as three maintenance welders can can work in a 20- x 30-ft. room without too much crowding, though the room size cannot be much smaller than that because of the objects that are built and repaired in the room.

A word about safety: As everyone connected with welding knows, the rays of the arc can give a very bad burn to both skin and eyes if they are sufficiently exposed. The room should be arranged with drop curtains between operators (better than screens) and a lightproof, fireproof, nonreflecting wall entirely surrounding it. Booths are an obstruction and a nuisance in a maintenance weldery and are not at all satifactory for job work. Enough ventilation must be provided to keep the fume concentration down to a nonhazardous minimum. While I have never seen it done, I have always felt that a welding room could be exhausted from floor level in the same manner in which we used a grill-work table top on a production job and exhausted the job through a suction pan and duct lying under the grill.

Various other things will suggest themselves to the man setting up such a shop, such as water- and oil-cooling tanks, lime and charcoal box, electrode and rod storage cabinet, etc. All these can be left to the welder's ingenuity and supplied as he needs them. As a rule, scrap accumulates rapidly in the weldery, so a junk pile for source and discard of salvage materials should be situated not too far away.

Accounting Setup

Concerning charging off wages and overhead to the various departments, I personally feel that too much emphasis has been placed by many companies on the matter of accounting for the distribution of shop costs. Some use a flat percentage figure based on man-hours chargeable to the job. This is not an entirely fair way of charging maintenance welding expense, for welders often use many times the amount of their wages in welding rod and material, while at other times they may weld all day on 50 cents' worth of rod. I believe that the actual or approximate amounts of gases, welding rod and time can be turned in to the timekeeper, who in turn, on consulting charts and adding a percentage to the actual cost of materials (power need not be counted), charges the job on a job basis against either the department, the product or the fund for which the job was done.

Concerning the charging off of wages and overhead to various departments served or products produced, I also feel that too much emphasis has been placed in some instances on the matter of the distribution of costs in tool room, maintenance department and maintenance weldery. While it is entirely possible to accurately charge off the labor and materials on a die or special jig for a very specialized production job, along with an estimated proportion of the overhead, it is an entirely different matter to fairly charge a particular product or department with, say, the repairs on a broken punch press frame or fractured crankshaft that may have been progressively failing for perhaps several years on many different jobs. Likewise, it would be equally unfair to charge the entire cost of a plating tank or parts conveyor to the particular item to be plated or conveyed, unless it were to be used continuously for millions of items on the

same job to which it was charged. While under average conditions I do not know of any entirely fair way of distributing costs, it seems to me that it would be well for the same sort of a purchase order and credit transfer to be used to pay for objects built in the maintenance weldery as is used for those built outside. Time spent in the repair end of the weldery could be chargeable to job or department on a labor and material plus overhead basis, but even then it would seem to me that the overhead on a 400-amp. arc welder should be greater per hour than, for instance, on an airplane type oxyacetylene torch. Then, too, excessive clerical and accounting costs can quickly reduce the savings and profits ordinarily obtained through the use of a company-owned maintenance weldery over the outside job shop type of service used by many companies who have not as yet established their maintenance weldery or are doing a haphazard welding job in tool room or general maintenance shop by unskilled, nonqualified weldors.

It has also come to my attention at different times that some sort of credit recognition should be kept for the savings in down time, delivery time, material and supply costs, labor, etc., which ordinarily are very outstanding in the maintenance weldery.

I remember a specific instance where under such a setup there would have been accredited to a two-man maintenance weldery in an automotive muffler plant $10,000 in production man-hours in a year's time which they effected using only a very small portion of their time in building bins, chutes, conveyors and other parts-handling and labor-saving equipment from scrap materials and production sheet steel. As it was, there was no credit given the weldery and at the end of the year its work was combined with the tool room and its personnel diverted into other channels. It is interesting to note that where the plant made a tremendous gain during that year (1937), the same plant with approximately the same business was reputed to have lost almost the same amount the following year (1938), which can be almost entirely traceable to added man power required to offset changed operating methods due to the rearrangement and obsolescence of much of this same parts-handling equipment built in this weldery which was no longer functioning.

At a later date, I had the opportunity to head a small maintenance weldery, where we constructed paint racks, trucks and parts-handling equipment, besides taking care of breakdown and tool and die welding. Here again, an efficient system of accrediting savings to their source (the weldery) would undoubtedly have enlarged the scope of usefulness of the maintenance weldery in that shop.

While it has been impossible to point out all advantages of the maintenance weldery over outside job shop service for the same work, possibly the most outstanding advantage to the manufacturer is his ability to get what he wants when he wants it, instead of taking what he can get whenever someone can get it, for him as it has been in the past few years. Then, too, the conversion of junk to machinery with welding and Yankee ingenuity is another marked advantage, especially in these days of shortages when deliveries may be delayed for weeks on some item for lack of parts, when the maintenance welder who knows his job can usually substitute something that is available to do the job, many times even better than that of the original design.

It is obvious that the principles of welding mixed with common sense can save most manufacturers many times their cost each year in a maintenance weldery, organized somewhat along the above lines.

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Flame Hardening Locomotive Brake and Spring Rigging Pins and Bushings*

By B. W. Covell†

IN PREPARING this paper on flame hardening, what I have to say is based only upon my practical experience and observations.

Flame hardening, which is a simplified process of surface hardening steel, is rapidly increasing in a number of uses for wearing parts on locomotives and cars in the railroad industry. Through the introduction of this process, it was learned that parts susceptible to severe wear could be hardened along the wearing surfaces, thereby extending the service life materially, and reducing roundhouse repairs and replacements.

First experimental flame hardening on the Northern Pacific Railroad was confined to parts with flat surfaces, such as crosshead guides, chaffing castings, equalizers and saddles. Figure 1 illustrates the hardening of crosshead guides.

Later, links, coach journal box pedestal ways, gear rack teeth, gear teeth, etc., were included. Figures 2 and 3 illustrate hardening of the inside and exterior surfaces of a link.

The latest and yet somewhat in the experimental stage,

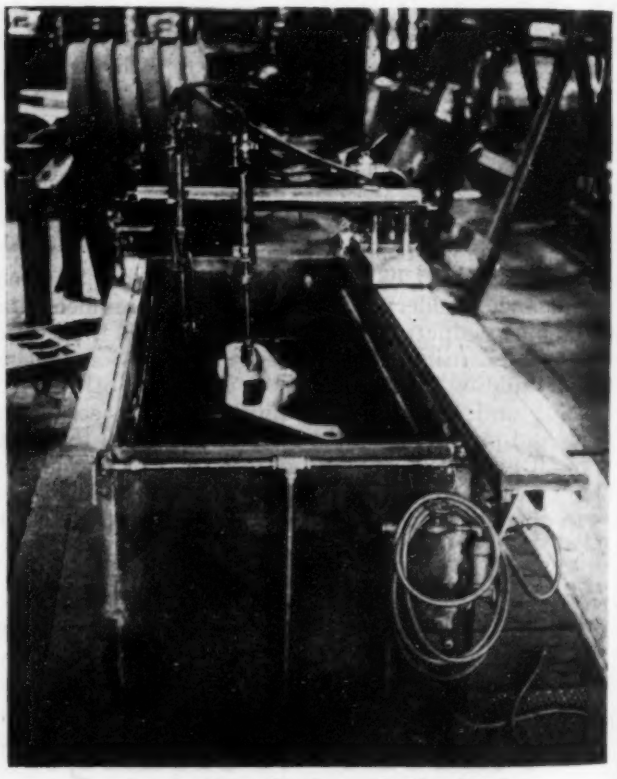

Fig. 2—Flame Hardening Inside of Link

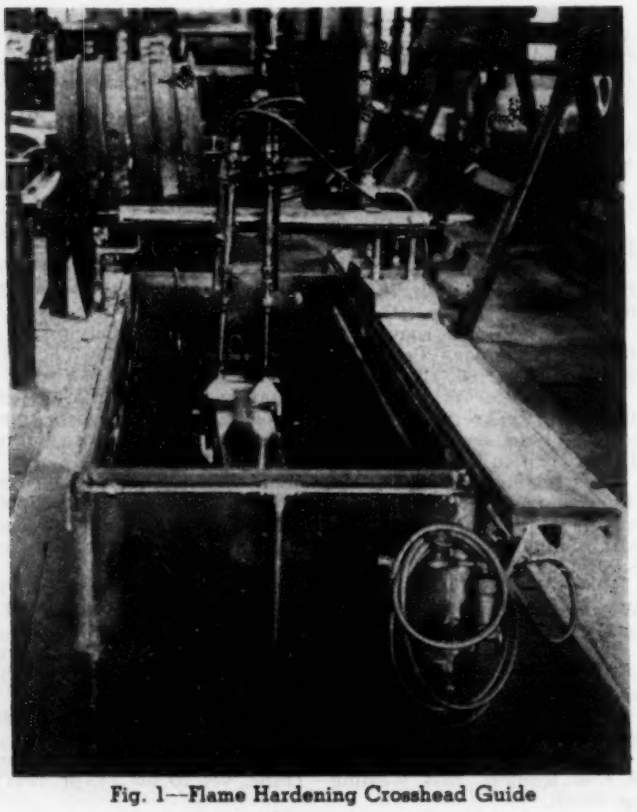

Fig. 1—Flame Hardening Crosshead Guide

is flame hardening locomotive brake and spring rigging pins and bushings. Figure 4 shows the hardening of a pin.

Satisfactory flame hardening of steel pins and bushings requires:

1. Correct quality of material.
2. Proper flame-hardening equipment.
3. A properly trained operator.

Quality of Material

Based upon our experience and tests, the best results with flame hardening of steel are obtained with S.A.E. 1040–1060 steel.

Since we have done very little experimental flame hardening of alloy steels, we cannot comment on the use of such material.

The material used for flame-hardened pins and bushings is within the range of 1045–1055 steel, and permits quenching within the wide range of 1470 to 1670° F.

* Scheduled for Twenty-Eighth Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 19, 1947.

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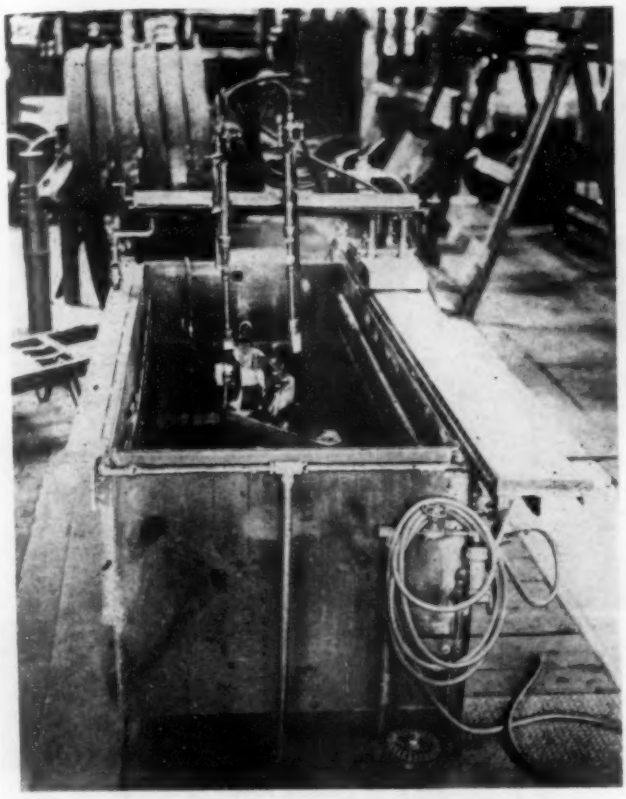


Fig. 3—Flame Hardening Exterior Surface of Link

Required Flame-Hardening Equipment

1. An ordinary motor-driven engine lathe capable of giving carriage speeds from 5 to 10 in. per minute.
2. A three-jaw and four-jaw self-centering chuck to permit handling hexagon, square and round stock to be hardened.
3. A jig mounted on the lathe bed consisting of a set of rollers, driven from the head stock for rotating the bushings.
4. A support mounted on the lathe carriage for holding the torches and water jets. This item permits centering the tips around pins and inside of the bushings.
5. Oxyacetylene apparatus consisting of:

2—Oxygen regulators (high capacity).
2—Acetylene regulators (high capacity).
2—Flame-hardening torches (water cooled).
2—Lever type valve blocks.
2—90° torch mixer extensions.
2—Required lengths of hose for both oxygen and acetylene. Torch tips for various size pins and bushings. Equipment is shown in Fig. 5.

At the time we started experimental flame hardening of pins and bushings, manufacturers of such equipment did not have anything to offer in the line of tips. Therefore, in order to get started we had to make our own tips. These were made from scrap cutting tips, mounted in a cast-bronze body. In order to harden the pins close to the head, the tips were set at an angle of 30° to the bronze body. This arrangement is shown in Fig. 6.

Flame-Hardening Process

The process used for hardening both pins and bushings is called the "progressive spinning method." This consists of revolving the parts from 250 to 300 rpm., while the flame and quenching medium pass over the area to be hardened. Revolving the parts gives an equal distribution of heat, thereby insuring uniform depth and degree of hardness.

The flame-hardening tips encircle the pins and are designed to pass both flame and quenching medium. No auxiliary quench is required if the quench is sufficient to immediately chill the part being hardened. Insufficient quenching will reduce the actual hardness of the exterior surface of the pins.

Flame hardening a pin is shown in Figs. 7 and 8.

The lathe is equipped with an adjustable gage for centering the opposite end of the pin from the chuck. After setting for one pin dimension, no further centering is required until different sizes of pins are to be hardened.

A lathe carriage speed of 6 $^1/_2$ in. per minute was used with carriage traveling away from the head. Only sufficient water is used to keep the tips cool until the critical temperature of the pin is reached, then the lathe carriage is put in motion and the valve controlling the quenching medium is opened.

Bushings are revolved on rollers driven from the lathe head. A longitudinal speed adjusted to $6^1/_2$ in. per minute is used with the carriage traveling toward the lathe head. Due to the thinness of bushings, an auxiliary quench cooling the external area is required to avoid hardening the entire wall thickness. Figure 9 illustrates method of flame hardening.

A ratio of approximately 1.7 oxygen to 1.0 acetylene gives the best heating results, producing a slightly oxidizing flame of approximately 6000° F. After this setting is obtained, it is further controlled from the valve block.

Skilled Operator

Operators for all classes of flame hardening should be skilled, and under the direct supervision of someone with knowledge of flame hardening.

Operators must be thoroughly familiar with proper manipulation and maintenance of oxyacetylene equipment and the instructions covering the use of such equipment.

Proper regulation of oxyacetylene flame and quenching medium for satisfactory flame hardening is most essential.

The operator should have a good knowledge of the quality of steel being hardened, the proper time cycle required for heating and a good judgment of surface temperatures. It is most important to avoid over or insufficient heating. Judging temperature by color under the torch flame is difficult and deceiving on account of the glare. Frequent hardness readings should be made to insure uniform results.

Laboratory Test of Pins

Comparable tests of flame-hardened and case-hardened pins were made; the case-hardened pins were treated by the pack-hardening process.

The number of coupons and tests results are as follows:

3 Bars, 2 × 10 in., S.A.E. 1045 steel, machine finished, flame hardened.
3 Bars, 2 × 10 in., S.A.E. 1045 steel, as rolled, flame hardened.
3 Bars, 2 × 10 in., S.A.E. 1020 steel, machine finished, case hardened.

Steel Analyses

Flame-hardened bars:	Pack-hardened bars:
Carbon, %—0.47	Carbon, %—0.24
Manganese, %—0.73	Manganese, %—0.45

Fig. 4—Flame Hardening a Pin

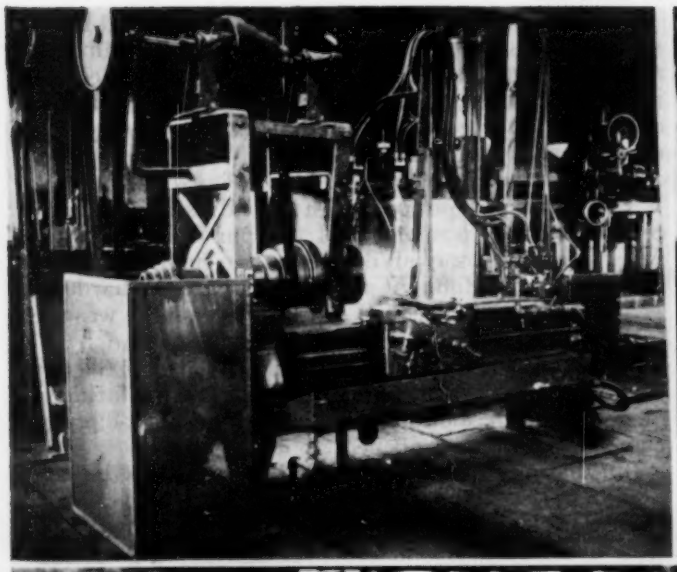
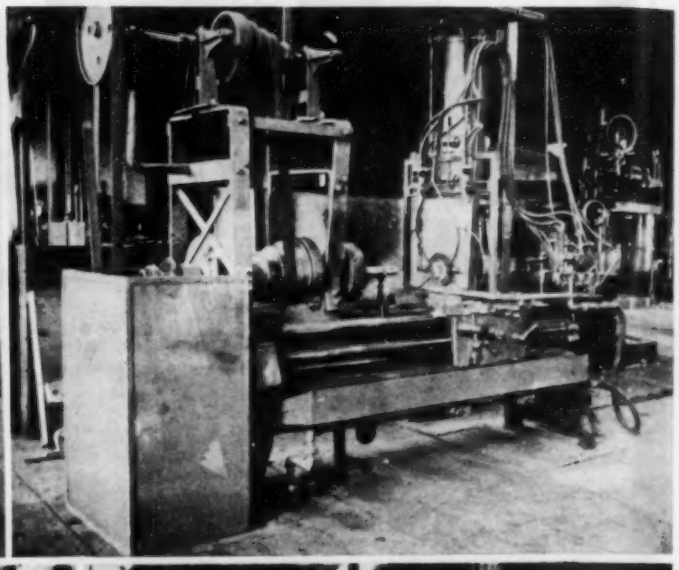


Fig. 5—Equipment or Flame Hardening Pins



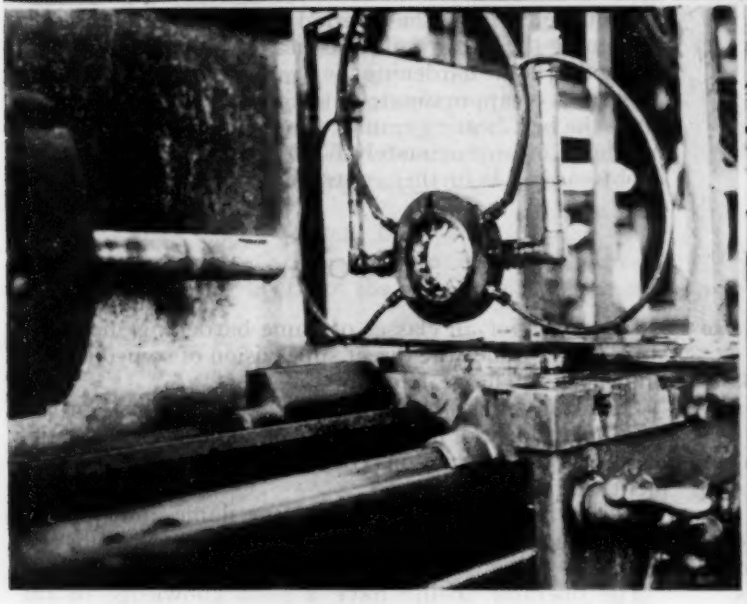


Fig. 6—Tip Arrangement for Pins

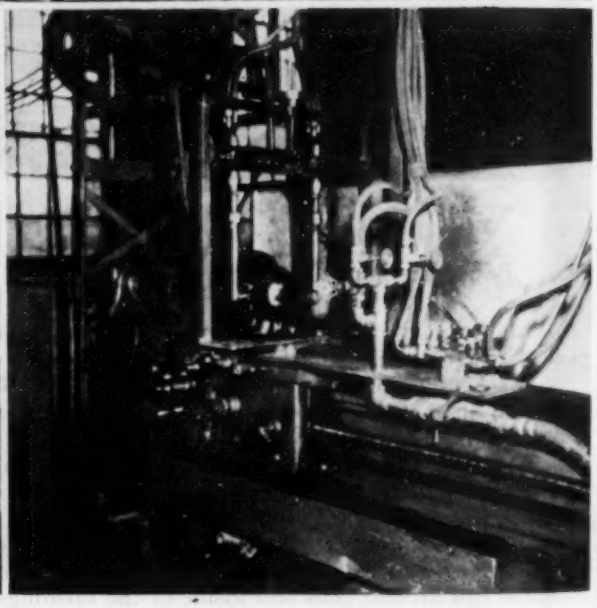


Fig. 7—Flame Hardening Pin. End View

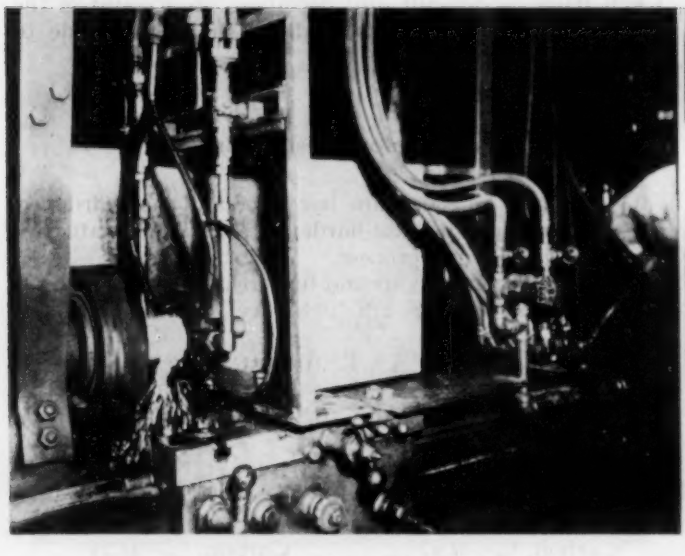


Fig. 8—Flame Hardening Pin. Side View

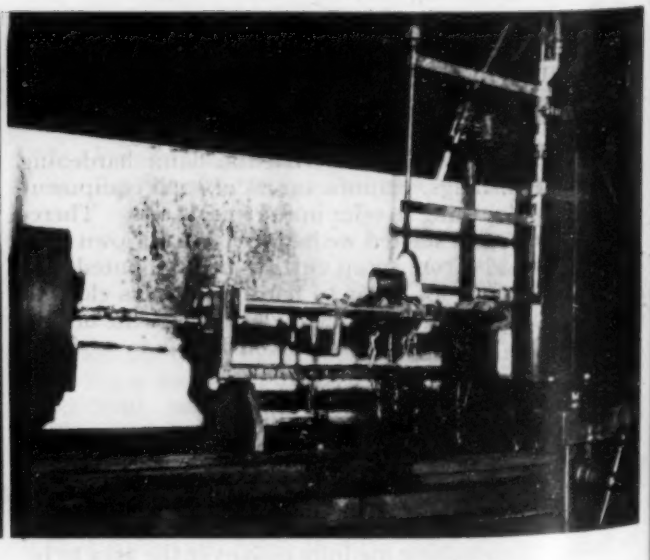
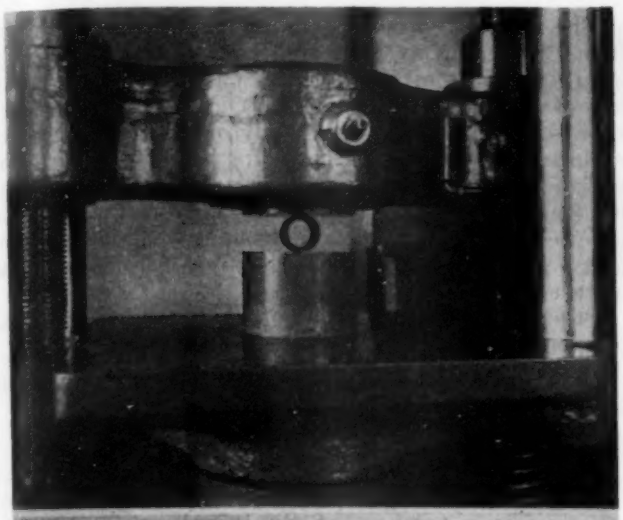


Fig. 9—Flame Hardening a Bushing

Fig. 10—Crushing Bushing for Deflection Data



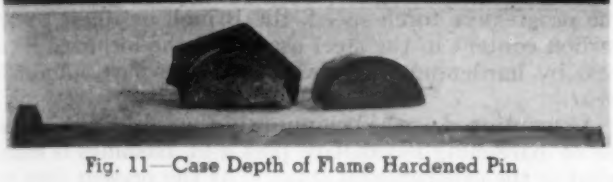


Fig. 11—Case Depth of Flame Hardened Pin

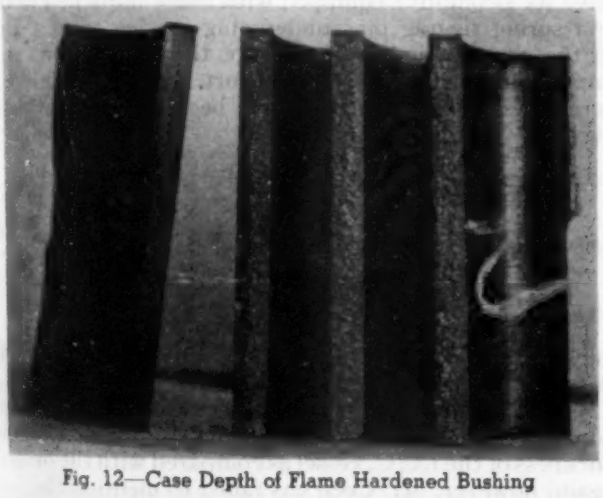


Fig. 12—Case Depth of Flame Hardened Bushing

Hardness, five reading average:
Flame-hardened, machined bars, Rockwell "C" 55, Brinell 567.
Flame-hardened, bars as rolled, Rockwell "C" 52, Brinell 534.
Case-hardened, bars machined, Rockwell "C" 56, Brinell 578.

Average depth of hardness:
Flame-hardened machined bars, $^{7}/_{64}$ in.
Flame-hardened bars as rolled, $^{7}/_{64}$ in.
Case-hardened, machined bars, $^{3}/_{64}$ in.

The depth of hardening was greater in the case of the flame-hardened bars. Case depth of flame-hardened pin sections is shown in Fig. 11.

Laboratory Test of Bushings

Comparable tests of flame hardening and pack case hardening bushings were made and the results can be summarized as follows:

4 Bushings, 2 x $2^{1}/_{2}$ x 3 in. flame hardened internally.
4 Bushings, 2 x $2^{1}/_{2}$ x 3 in. pack hardened.

Steel Analyses

Flame-hardened steel:	Pack-hardened steel:
Carbon, %—0.51	Carbon, %—0.22
Manganese, %—0.77	Manganese, %—0.45

Micrometer readings before and after hardening showed a 0.003-in. average shrinkage on all specimens with no noticeable distortion.

Crushing Test

Average deflection under load in inches:

Flame-hardened bushings at 5000 lb. pressure deflected 0.012 in.; at 10,000 lb. deflected 0.026 in.; failed at 12,025 lb. with 0.044-in. deflection.

Case-hardened bushings at 5000 lb. pressure deflected 0.012-in.; at 10,000 lb. deflected 0.024 in.; failed at 14,630 lb. with 0.040-in. deflection.

Crushing a bushing is illustrated in Fig. 10.

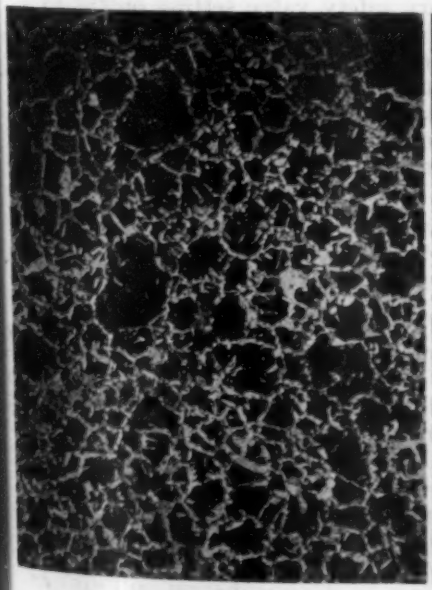


Fig. 13—Pearlite Structure of Bushing Material

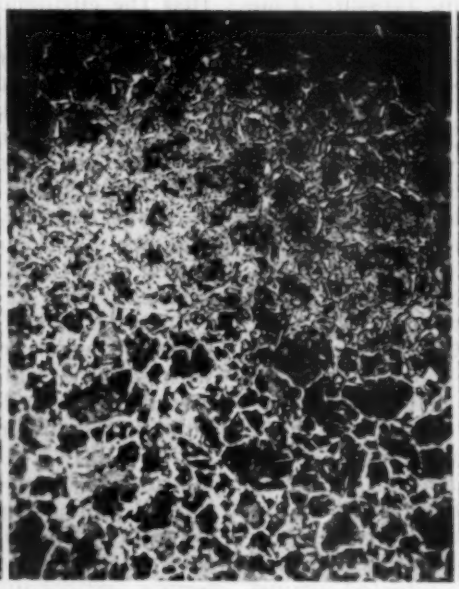


Fig. 14—Material Structure Change in Hardened Area

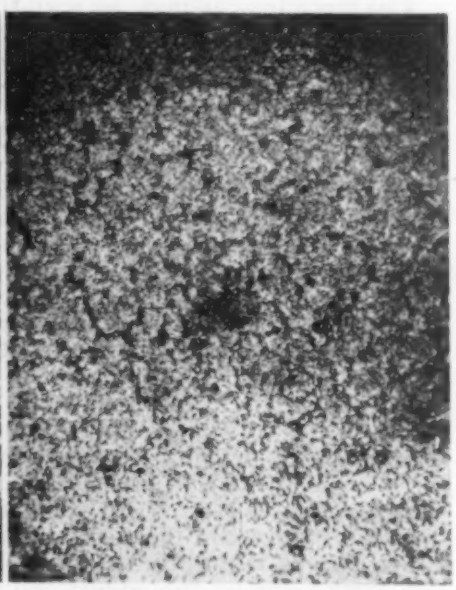


Fig. 15—Martensitic Structure in Hardened Metal

Hardness average, 12 readings per bushing:

Flame hardened	Rockwell "C," 62 average
Case hardened	Rockwell "C," 65 average

Depth of Case:

Flame hardened	Case depth, 0.060 in.
Pack hardened	Case depth, 0.050 in.

Case depth of flame-hardened bushing sections is shown in Fig. 12.

The flame-hardened bushings showed a more uniform hardened surface, the readings varying but four points. The hardness varied considerably on the pack-hardened bushings and the three highest reading averages per quarter section of the bushing tested were taken.

You will also notice, in comparing the hardness Rockwell "C" 55, from material of carbon content 0.47% as used in the pins with the Rockwell "C" 62 from a steel of carbon content 0.51% as used in the bushing, that the carbon percentage is essential if a given hardness is to be obtained.

The three following illustrations show the steel structure of a flame-hardened bushing in the normal and flame hardened stage:

Figure 13 shows the structure of the normal metal consisting of pearlite with free ferrite in the grain boundaries.

Figure 14 shows line of demarcation between the soft normal metal consisting of pearlite with free ferrite in the grain boundaries, and the flame-hardened metal consisting of martensite.

Figure 15 shows the martensitic structure of the flame-hardened metal.

Advantages of Flame Hardening

The most important advantage is the time saved by flame hardening as compared with pack hardening for small quantities of parts. With pack hardening regardless of a partial or full furnace charge, the carburizing time is the same and, where only one shift is employed, requires about three days, one for packing, one for carburizing and the third for heat treating. With flame hardening, pins can be hardened in from three to five minutes each and the average bushing in about two minutes. For large quantities, the time period would be more equal.

Other flame-hardening advantages deserving consideration are:

1. Controlled hardness penetration ranging from $^1/_{64}$ to $^1/_4$-in.
2. Brinell hardness as desired.
3. Localized hardness.

The controlled hardness penetration is governed by the progressive torch speed, the Brinell hardness by the carbon content in the steel used, and the localized hardness by hardening only the area of the part subject to wear.

As mentioned at the beginning of the subject, this process of hardening locomotive pins and bushings is somewhat in the experimental stage. At the present time we have six locomotive equipped with flame-hardened brake and spring rigging pins undergoing service tests. Due to the short period of time since the application, it is impossible to give a service report. To date only experimental laboratory tests have been made with bushings.

Comment on article by R. E. Cecil

(*Continued from page 906*)

would make possible the application of 375 psi. pressure.

This regulation, allowing an operating pressure of one and one-fourth times the rating of the tank, is the basis under which Dr. Martel of California Institute of Technology figured comparative stresses in I.C.C. and A.P.I.-A.S.M.E. vessels.

Dr. Martel's comparison of the I.C.C. formula with the A.P.I.-A.S.M.E. formula for stresses in the shell plates is on record in the Transcript of Public Hearings for Proposed Revision of California State Liquefied Petrolem Gases—Safety Orders. The hearings were held in Los Angeles Aug. 6 and 7, 1946.

As Mr. Cecil says, of course, the A.P.I.-A.S.M.E. vessels with a shell seam are necessarily heavier in the eyes of the law inasmuch as no welded seam is recognized by the A.P.I.-A.S.M.E. code as being as strong as the shell itself. He goes on to say that liquefied petroleum gas is noncorrosive so that no added wall thickness is required on that score. He does not mention that corrosion on the outside of the container can be a very definite safety factor where containers are used for domestic storage and therefore not subject to periodic inspection and frequently used without proper precaution as to being off the ground and protected against exterior corrosion.

Then Mr. Cecil gives a tabulation for minimum shell thicknesses on $14^1/_2$ in. I.D. I.C.C. 4B240, which he classifies as for 240 psi. and the same diameter A.P.I.-A.S.M.E. and A.S.M.E. U201 psi. vessels. This tabulation, of course, shows a very small difference in the thickness of the I.C.C. vessel as compared with the others. Again, however, Mr. Cecil has failed to mention the fact that the customary safety valve setting on the I.C.C. vessel is 375 psi. while the other two codes specifically require a maximum setting of 240 psi.

The whole discussion by the California Liquefied Petroleum Gas Tank Manufacturers at the public hearing Aug. 6, 1946, mentioned by Mr. Cecil, was based on a compararison of safety of the codes. As long as the I.C.C. containers can and do have their safety relief valves set at 156% of the so-called working pressure, from a safety standpoint the I.C.C. 4B240 is actually 56% lighter than the A.P.I. vessel carrying the same factor of safety.

In order to safely meet pressures encountered with liquefied petroleum gases now being used commercially with safety, California tank manufacturers as well as manufacturers all over the United States have been building liquefied petroleum gas tanks to at least 250 psi. under A.P.I.-A.S.M.E. and A.S.M.E. U201 codes. If mixtures of liquefied petroleum gases should be changed to still higher vaporizing pressures, as they very well may, then these tanks will have to be built to still higher working pressures while the 4B240, which are in domestic service and not under I.C.C. jurisdiction, will still operate at these higher pressures because the safety valves will not open until 375 psi. have been reached.

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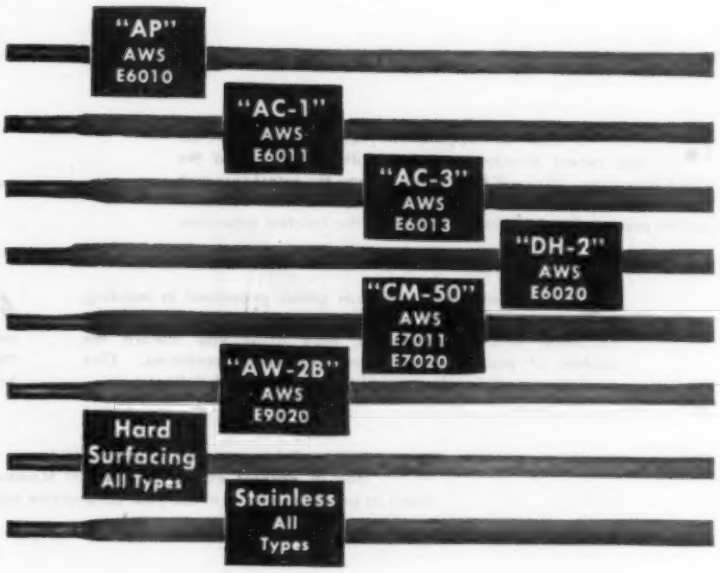

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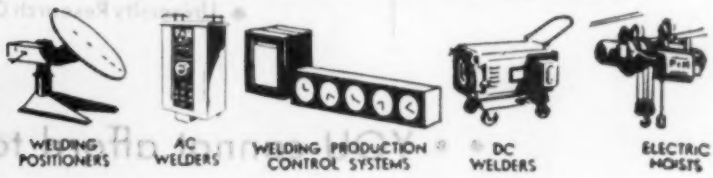

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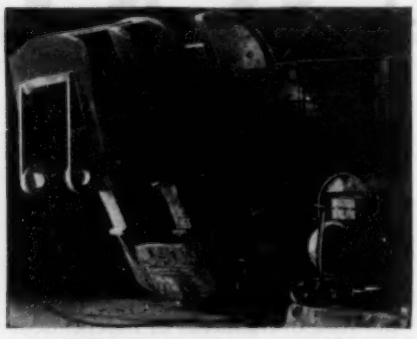

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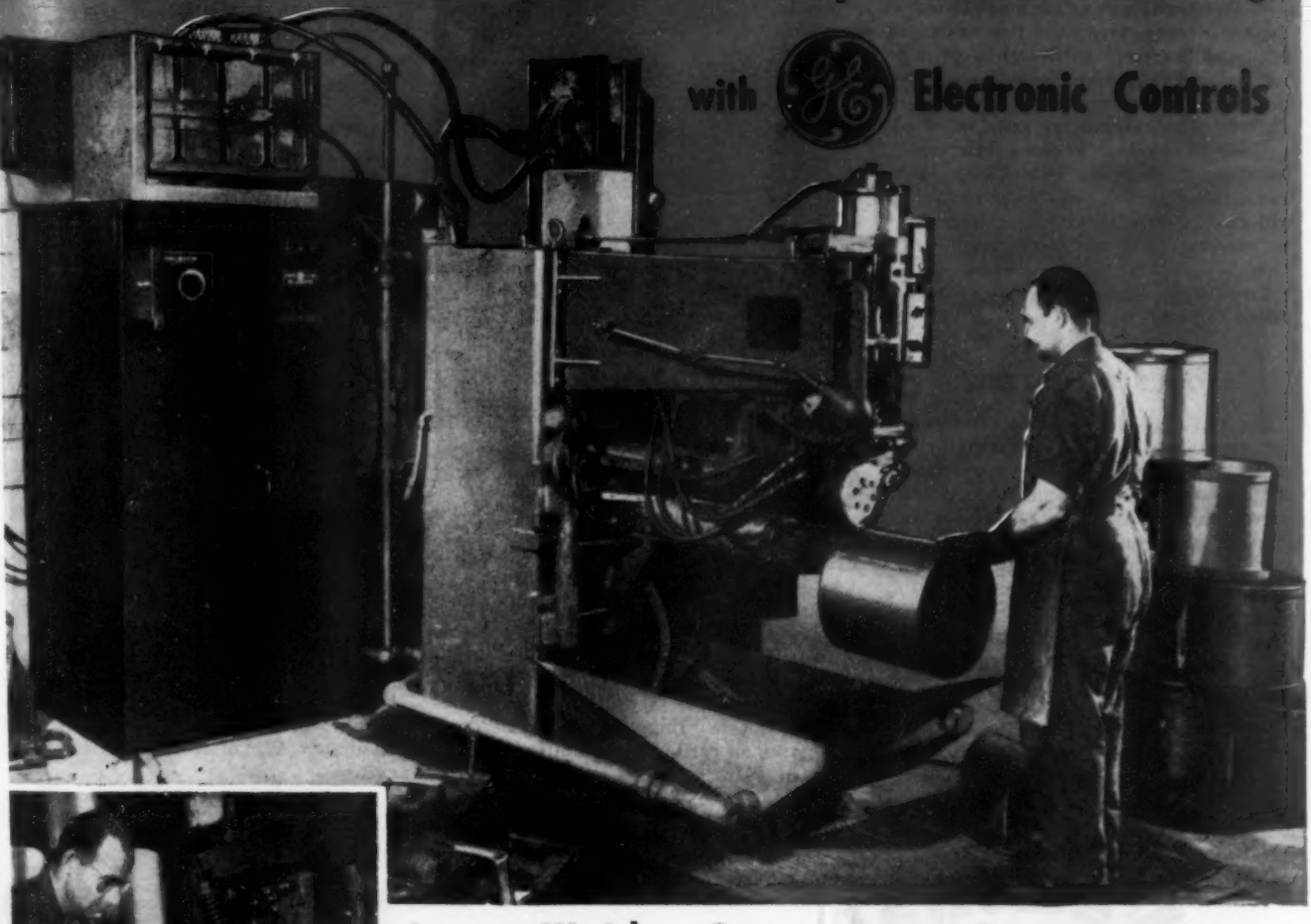

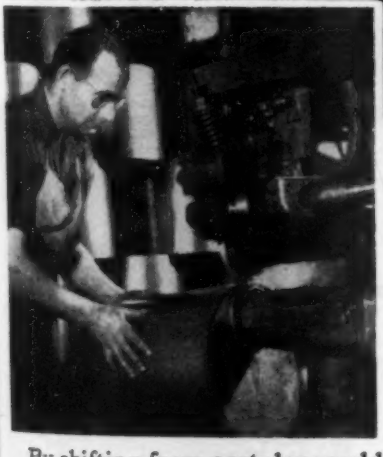

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KNOW YOUR SOCIETY

Beginning with this issue, J. G. Magrath, our new Executive Secretary, in consultation with members of the staff and others, will portray each month one of the important activities of the AMERICAN WELDING SOCIETY. Although most of us are thoroughly familiar with these activities, we often take them for granted. This information will not only be of assistance to members in more fully understanding the benefits, value, importance and accomplishments of their Society, but will also provide them with ammunition to convince others that they should "join."

Comments, suggestions and criticisms will be welcome.

OUR NEW PRESIDENT

Mr. Harold O. Hill, elected President of the AMERICAN WELDING SOCIETY, brings to that office not only a keen appreciation of the problems confronting the SOCIETY gained through his service as Director and, Vice-President, but also a wealth of experience in committee work of the SOCIETY. He served as Director-at-Large during the years 1940 to 1943; as Vice-President from 1944 to date and as a Member of the Executive Committee for the past nine years.

Mr. Hill is Assistant Chief Engineer, Fabricated Steel Construction, of the Bethlehem Steel Co., at Bethlehem, Pa. Born in Ontario, Canada, he was educated

Harold O. Hill

at the University of Toronto, from which he received the degree of B.A.Sc. in Mechanical Engineering.

He commenced his engineering career with the Riter-Conley Co. of Pittsburgh, Pa., fabricators of plate and structural steel. Here he served in many capacities and was Chief Engineer when this company was merged into McClintic-Marshall Co. in 1916, when he became Assistant Chief Engineer of the enlarged company in charge of the engineering on tank and platework. When the McClintic-Marshall Co. was emerged with the Bethlehem Steel Co. in 1931 he continued his same duties with the Bethlehem Steel Co.

Other engineering activities include the chairmanship of the A.W.S. Committee, which prepared "Rules for Field Welding of Storage Tanks"; chairman of the A.P.I.-A.W.S. Conference Committee on the Welding of Storage Tanks; member of the A.W.S. Symbols Committee; member of the A.W.S. Committee on Standard Qualifications Procedure; member of the A.W.S.-A.W.W.A. Committee on Specifications for Field Welding of Steel Water Pipe Joints; member of the A.W.W.A.-A.W.S. Conference Committee on Elevated Steel Water Tanks, Standpipes and Reservoirs; member and past-chairman of the A.W.S. Technical Activities Committee; member of the A.W.S. Committee on Honorary Memberships and Honorary Directorships; chairman of the Special Committee appointed by the Board to study the future needs of the SOCIETY, which recommended strengthening of the Headquarters Staff, which led to the recent selection and employment of an Executive Secretary for the SOCIETY; Member of the A.P.I., A.S.T.M., A.I.E.E., A.S.C.E., A.S.M.E., A.W.W.A., a registered professional engineer in the State of Pennsylvania and past-president of the Bethlehem Rotary Club. Mr. Hill has been a member of the AMERICA WELDING SOCIETY for sixteen years.

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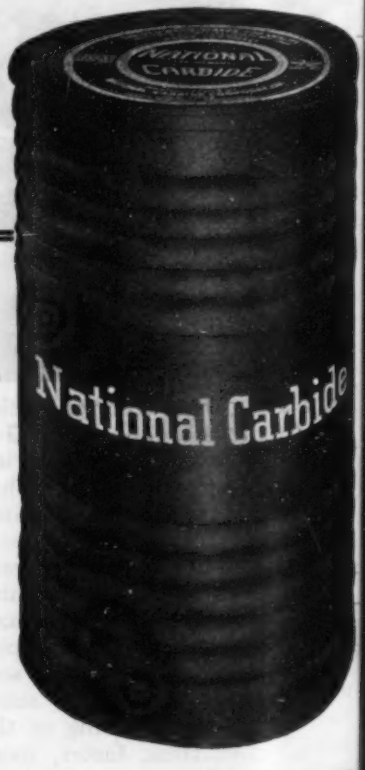

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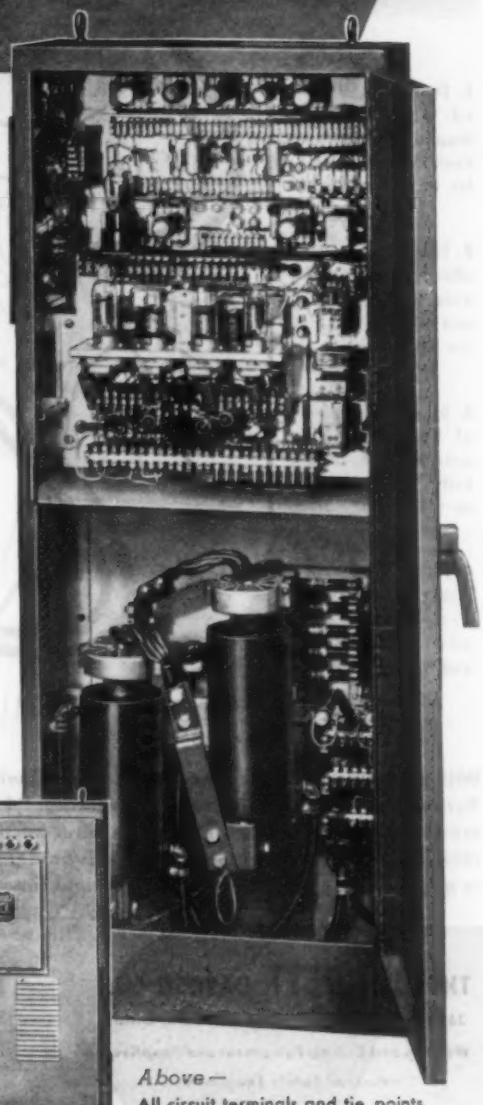
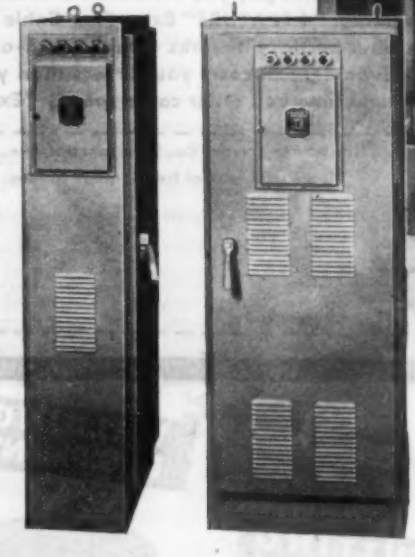


Above—
All circuit terminals and tie points accessible by opening main door and swinging out sequence panel.



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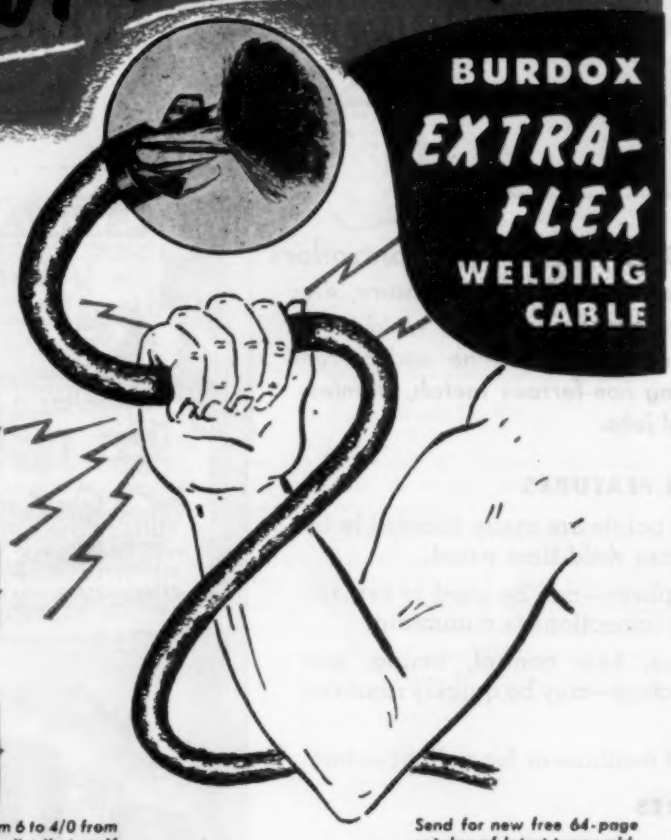

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JOHN F. CALLAHAN COMPLETES 30 YEARS WITH AIRCO

John F. Callahan, assistant advertising manager of Air Reduction celebrated his 30th Anniversary with that firm on August 11th.

He was the guest of honor at a luncheon held at the Uptown Club by members of the Advertising Department. During the luncheon Mr. Callahan was presented with a Gruen wristwatch and a scroll commemorating his 30 yr. of continuous and able service.

Mr. Callahan started with Air Reduction in 1917 and entered the Advertising Department in 1920. For a number of years he served as field representative. Later, he became widely known throughout the United States as Air Reduction's convention specialist.

An active member of the National Industrial Advertisers Association, the AMERICAN WELDING SOCIETY and the International Acetylene Association, Mr. Callahan was appointed assistant advertising manager in 1939 and continues to serve in that capacity.

WELDING PATENTS

A classification system for the more than 11,000 welding patents now in the Davis Welding Library at Ohio State University was established this summer, according to Dean Charles E. MacQuigg of the College of Engineering.

In charge of the project, which will enable industries, students and research workers to obtain more readily information on all patents granted in their specific lines, is Dr. W. H. Simon of the University of Toronto.

Cost of the work is being paid from the A. F. Davis Welding Engineering Scholarship and Library Fund. Mr. Davis, vice-president of the Lincoln Electric Co., Cleveland, and an alumnus of Ohio State University, established the welding library a number of years ago and at the same time set up such a scholarship fund.

The library includes a large collection of patents relating to the Welding processes and their industrial applications. At present the patents are grouped according to the classes and subclasses of the U. S. Patent Office, set up years ago when welding was in its infancy. The great increase in recent years in the number of patents in this field has made it difficult to locate patents relating to specific subjects. The new classification system will remedy the difficulty.

Dr. Simon has done considerable work in the patent field and has published some of his studies in book form. He received his Ph.D. at the University of Sheffield in 1939 where his work was in the field of Welding Metallurgy. He was awarded a prize by the Institute of Welding, London, England, for his dissertation "Arc Welding Electrodes and Their Relations to the Weld Metal."

A member of the AMERICAN WELDING SOCIETY, Dr. Simon also is an associate of the Institution of Mechanical Engineers and a member of the Ontario Association of Professional Engineers.

He needs

REVERE No. 456 LOW FUMING

Bronze Welding Rod

WHY put up with bothersome fumes when you can produce strong welds quickly with Revere No. 456 *low fuming* bronze welding rod?

This "flame-tested" rod is particularly useful in joining, without fusion, base metals of higher melting points. In the welding of cast iron, Revere No. 456 saves time and fuel because its low melting point (about 1600° F.) reduces the need for high pre-heats and post-heats. And Revere No. 456 gives you sound joints in the bronze welding of cast and malleable irons, wrought iron, cast and wrought steel, cast and wrought bronze.

Other Revere Welding Rods are: RevereBronze380, ManganeseBronze, Herculoy, Phosphor Bronzes, Brass (Brazing Rod), Silicon Deoxidized Copper and Electrolytic Copper. All come in 100-pound cases or in 25-pound cartons, net weight, and are stocked by Revere Welding Rod Distributors in all parts of the country. Write for folder giving technical data and net prices.

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OUR FIRST VICE-PRESIDENT

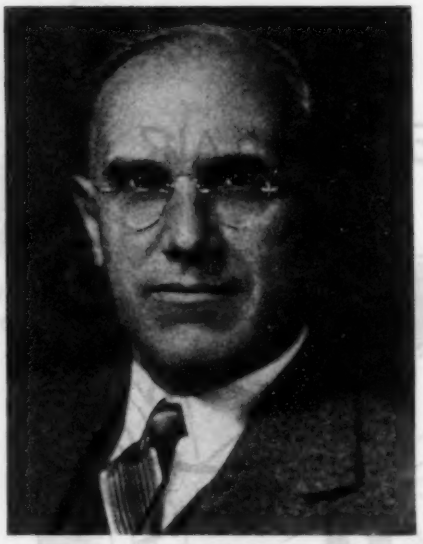
George N. Sieger is a graduate of Lehigh University, with the degree of Electro Metallurgist.

Prior to the First World War, he served with the Davis Bournonville Co., Electrolytic Oxy-Hydrogen Dept. As a matter of fact, he had charge of a large installation of their equipment in France.

Upon return to the States after the First World War, Mr. Sieger rejoined P. R. Mallory and was associated with this company in an executive capacity from 1919 to 1933. During this time he took part in the formation of the Carboloy Co. and served as assistant to the president during the period that the Mallory organization controlled its activities.

Mr. Sieger's association with the AMERICAN WELDING SOCIETY dates back many years. He has taken an active part in the Detroit Section since the formation of his own company 14 yr. ago, the S-M-S- Corp. of which he is president and general manager.

During World War II, he served as chairman of the Task Committee, Resistance Welding Electrodes Advisory Committee and as a member of the Task Committee of Resistance Welding Machines Advisory Committee, WPB. Also, he was attached to the Cutting Tools Section staff of WPB as consultant on Cemented Tungsten Carbides. Has made many presentations on Cemented Carbide, Elkonite, Resistance Welding and its electrodes before technical societies, luncheon clubs, etc.



George N. Sieger

Mr. Sieger is a past president of the Alloy Group, RWMA, and presently serving as president of the RWMA. He is a member of A.S.M., S.A.E. and E.S.D.

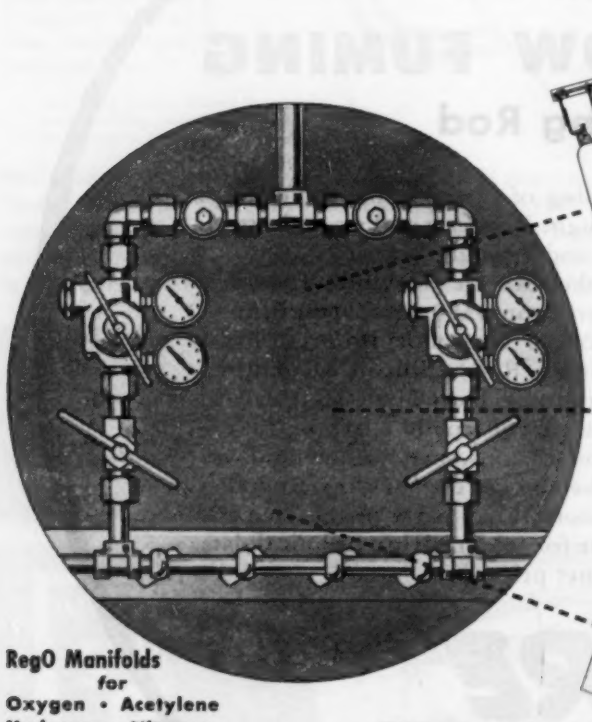
OUR SECOND VICE-PRESIDENT
O. B. J. Fraser

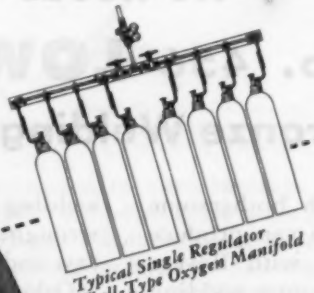
O. B. J. Fraser is Assistant Manager of the Development and Research Division of the International Nickel Co.

For the past thirteen years Mr. Fraser has been Director of Technical Service on International Nickel's Mill Products, and since March 1945 he has also headed the Industrial Chemicals Section of the Development and Research Division in New York Mr. Fraser for some years has been directing International Nickel's investigational work at Mellon Institute of Industrial Research Pittsburgh, Pa., on certain problems in the chemistry and technology of nickel.

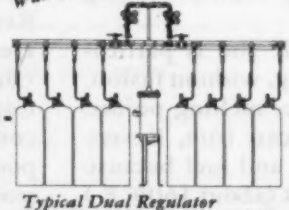
He joined the company in July 1917 as metallurgical engineer at the Bayonne,

O. B. J. Fraser

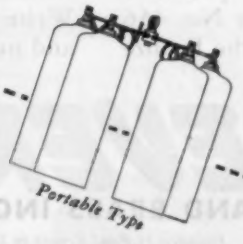




Typical Single Regulator Wall-Type Oxygen Manifold



Typical Dual Regulator Floor-Type Acetylene Manifold



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Extra Convenience... standard RegO Manifold construction provides individual shut-off valves at each cylinder station...this design permits any one cylinder to be disconnected without shutting down the entire manifold. Master shut-off valves control each main branch.

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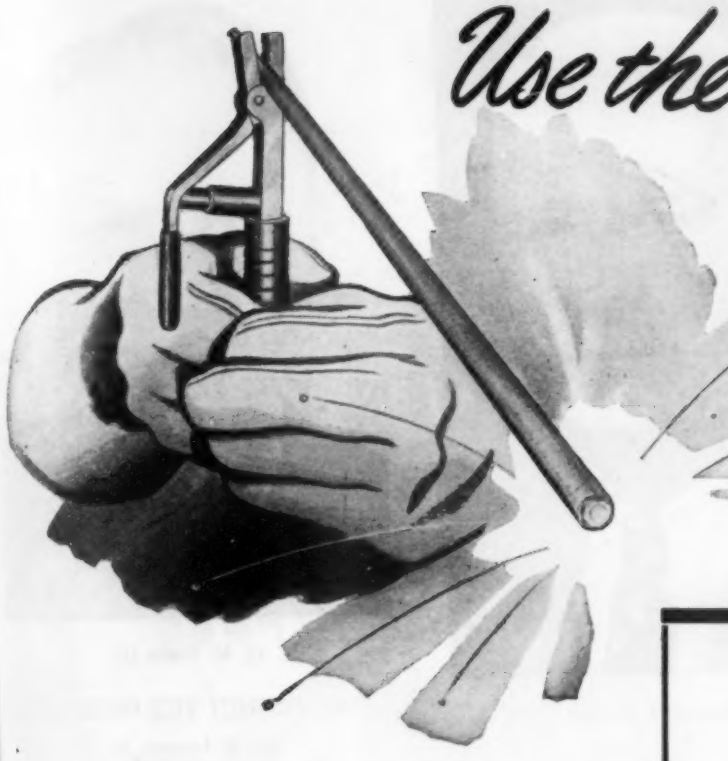

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HAYNES hard-facing alloys with greatly improved coatings are now available for metallic arc welding. Use them on your next job to protect metal parts from abrasion, heat, and corrosion.

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One of These HAYNES Hard-Facing Rods Will Do Your Job

1. HAYNES STELLITE Rods . . . cobalt-chromium-tungsten alloys . . . high in red hardness and highly resistant to abrasion and corrosion.
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5. HASTELLOY Rods . . . nickel-base alloys . . . resistant to heat and abrasion and highly resistant to corrosion.

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HAYNES TRADE-MARK *alloys*

N. J., works. In April 1918 he was transferred to the company's Port Colborne, Ontario, works and became successively superintendent of the Electrostatic Fume Precipitation Plant, night works superintendent and research engineer. During 1922, while still with the company he became associated with the Mellon Institute in the study of corrosion of nickel and nickel alloys. Mr. Fraser was placed in charge of the Research Laboratories of INCO at Bayonne in 1924, remaining in that position until 1932. During the next two years he carried on field development work in the use of nickel alloys in the petroleum industry. His first contact with the Canadian nickel industry was in 1914 in exploration work in the Sudbury, Ontario, nickel district at the Levack Mine.

Born in Brookville, Ontario, he received a B.Sc. degree in metallurgical engineering in 1916 from Queen's University, Kingston. During World War I, Mr. Fraser served in the Canadian Field Artillery and was an inspector of military explosives in Canada for the Imperial Ministry of Munitions of Great Britain.

Mr. Fraser is actively identified as both officer and member of committees of a number of metallurgical and engineering organizations. He served as National Treasurer of the AMERICAN WELDING SOCIETY, vice-chairman of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers, and is a member of American Society of Mechanical Engineers, American Institute of Chemical Engineers, American Chemical Society, Electrochemical Society, American Petroleum Institute (Technical Section), American Gas Association (Technical Section), Electroplaters and Depositors Technical Society, American Society for Metals, American Society for Testing Materials, American Association for the Advancement of Science and Electrodepositors Technical Society of London. He is author of several technical publications.

OUR NEW TREASURER

The AMERICAN WELDING SOCIETY is fortunate to secure the services of Russell S. Donald to act as its treasurer. Mr. Donald is a man of extensive business experience. He was born on February 6, 1891. He started his business career as a tool maker and designer. He joined the Thomson Electric Welder Co. in 1909 and has been with the company ever since. He now holds the position of sales engineer.

In 1933 he organized the Electroloy Co., of which he is now treasurer, which organization does an extensive business in the manufacturing and supply of resistance-welding electrodes. He is also president of the Conlon Manufacturing Co., Bridgeport, Conn. This company specializes in the manufacture of rubber shoe machinery and general machine work.

Russell S. Donald

Russell Donald has been active in the AMERICAN WELDING SOCIETY for a great many years. He has served as a member of the technical committees interested in resistance welding and has been a member of the National Program Committee for many years. He has also served on the Board of Directors and on the Finance Committee. He has been elected as treasurer for a three-year period.

VICE-PRESIDENT—DISTRICT NO. 1

G. M. Trefts III

G. M. Trefts graduated from Cornell University in 1927 as an M.E. He worked with American Steel and Wire Co., Cleveland for 3 years to 1930. Since 1930 he has been connected with Farrar & Trefts, Inc., and at present is vice-president in charge of production. During his service with Farrar and Trefts, Inc., product of plant was shifted from almost all-riveted work to almost all-welded work consisting of all alloys and all types of high-pressure welded vessels.

For 2 years Mr. Trefts served as chairman of A.W.S. Western New York Section during which time membership was almost doubled.

G. M. Trefts III

3RD DISTRICT VICE-PRESIDENT

Roy E. Lorentz, Jr.

Mr. R. E. Lorentz, Jr., is associated with the Combustion Engineering Co., Inc., Chattanooga, Tenn., as assistant

Roy E. Lorentz, Jr.

"ELECTROLOY" for RESISTANCE WELDING

Butt
Flash
Spot
Seam
Projection

ELECTROLOY

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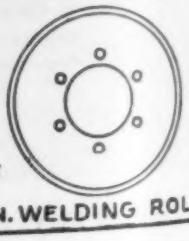

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BLUE DEVIL - E 6010
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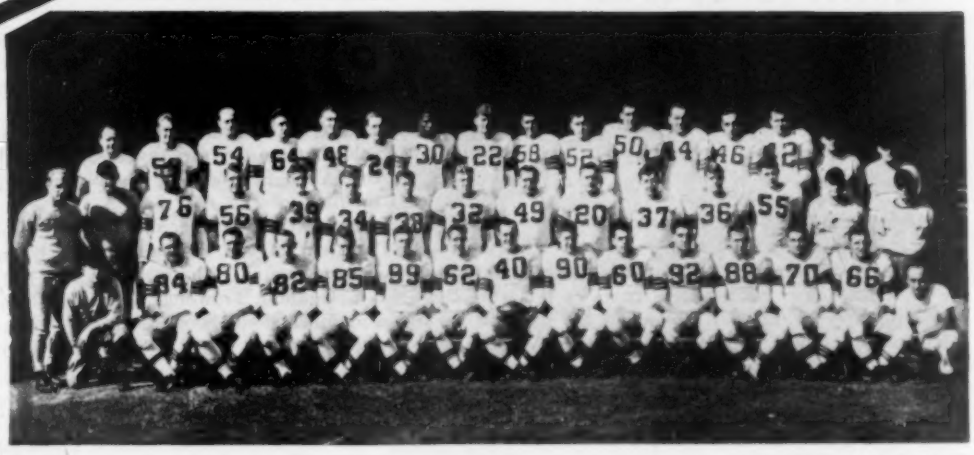
You can expect Star Performance from

A TEAM OF CHAMPIONS



CLEVELAND BROWNS—Champions of the 1946 All American Professional Football League.

A team of *Champion Welding Electrodes*, like a team of champion athletes, is dependable, versatile, rugged and fast. In all positions uniform performance and stamina contribute to that perfect co-ordination which licks the toughest jobs and scores a hit with the customers. For consistently top notch results on your welding problems remember "They Have to be Good to be CHAMPIONS."

Pierce Champion

THE CHAMPION RIVET COMPANY

CLEVELAND, OHIO — EAST CHICAGO, IND.

chief metallurgist. Mr. Lorentz first became interested in welding while working for Hollup Corp. in Chicago, where he learned electric arc welding with bare and coated electrodes and was thus enabled to spend subsequent summers during his training on various field and shop welding jobs.

Mr. Lorentz was born on March 29, 1916, in Champaign, Ill., and received elementary education in Chicago. He graduated in 1939 with the B.S. degree in metallurgy from the University of Illinois, and in 1940 received the M.S. degree in metallurgy from Lehigh University.

In June 1940 Mr. Lorentz went with the Combustion Engineering Co., Inc., at Chattanooga, Tenn., as welding metallurgist. He has been active in the Chattanooga Section of the A.W.S., serving as chairman in 1943. He has given several papers on welding before various engineering societies and published papers on welding subjects and radiographic testing.

In addition to membership in AMERICAN WELDING SOCIETY, he is also a member of A.S.M., A.S.T.M., Tau Beta Pi and associate member of Sigma Xi.

5TH DISTRICT VICE-PRESIDENT

J. R. Wirt

J. R. Wirt of the Process Engineering Department, Delco-Remy Division of General Motors at Anderson, Ind., has been elected Fifth District Vice-President of the AMERICAN WELDING SOCIETY.

A graduate of Purdue University, Mr. Wirt was employed by the Indiana Bell Telephone Co. before joining Delco-Remy in 1936. In 1938 Delco-Remy began development of a process to resistance weld steel tubing from $^{3}/_{16}$-in. diameter to $^{9}/_{16}$-diameter and Mr. Wirt was assigned to this project. Two years were spent in successfully completing this assignment.

In 1940 Wirt was named Welding Engineer for the Division and since that date has been identified with the development and expansion of welding, brazing and soft soldering processes in the Division's nine plants.

Wirt is a member of the A.W.S., A.S.M. and an associate member of the A.I.E.E.

J. R. Wirt

He is serving as chairman of the A.W.S. Brazing Committee, chairman of the Handbook Solder Chapter Committee, member of the A.I.E.E. Welding Committee and member of the A.W.S.-A.S.-T.M. subcommittee VIII on filler metals. He is Vice-President of the Indianapolis Technical Societies Council, Chairman of the Boy Scout Council Training Committee and a member of the Scout Council Executive Committee.

7TH DISTRICT VICE-PRESIDENT

Gilbert S. Schaller

Gilbert S. Schaller graduated from the University of Illinois with a B.S. in M.E. degree in 1916. Upon graduation, he was employed by the Kawneer Mfg. Co., Niles, Mich., in the production engineering department. While employed there, he developed a machine for welding tubing with a multiple tip torch—a development that played an important part

Gilbert S. Schaller

in aircraft tubing manufacture during World War I. After attendance in Officers' Training Camp at Fort Sheridan, Ill., he was commissioned in the Ordnance Dept. He served overseas for 18 mo. both with the AEF and as a staff officer in the Fourth French Army. Upon resumption of civil status, he was with the Mendota Manufacturing & Transfer Co. in production work and later joined the H. D. Conkey Co., as Factory Manager. From the latter position, he went to the University of Washington, Seattle, as an Instructor in Mechanical Engineering. In 1925, he earned the M.B.A. degree at that university. He is now Professor of Mechanical Engineering in charge of the manufacturing methods courses and laboratories.

Professor Schaller is a member of Tau Beta Pi, Sigma Xi and Chi Phi. Twice he has been chairman of the Puget Sound Section of the A.W.S. and a contributor to THE WELDING JOURNAL as well as other technical publications. He is a member and past chairman of the Puget Sound Chapter of the ASM, and a member of the AFA where he has served on several national committees. Among other pub-

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Sizes 1/4 to 300 KVA.

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Showing detail construction of tray made for Bridgeport Brass Co. by Rolock, Inc., Fairfield, Conn., from Inconel sheet. A group of 6 brake-formed channels are connected flexibly by 9 cross bars which serve as combination tierods and work supports. This construction provides for uniform heat and weight distribution . . . eliminates stresses and cracking tendencies . . . permits interchangeability of parts.

This tray broke a BRAZING BOTTLENECK

How to step up brazing-furnace production?

That's the problem Rolock, Inc. had to answer for the Bridgeport Brass Co. when they wanted to get more Aer-A-Sol "bug bombs" through their existing furnaces.

Replacing the production-losing weight of heavy, cumbersome fixtures was Rolock's solution.

How?

By fabricating strong, tough, lightweight, carriers made of INCONEL*.

This strong, workable alloy (80 nickel, 14 chromium), permitted a tray of unique articulated construction.

The tray designed by Rolock, Inc., withstands brazing temperatures. And, while only .047" thick, the Inconel sheet construction combines maximum rigidity with minimum weight. It offers ample strength to support the imposed load . . . and plenty of toughness to take rough handling.

Wrote Mr. Stanley G. Kroto, Mechanical Engineer of Rolock: *"The new all-Inconel trays have long life . . . and are more than fulfilling designer's expectations."*

Have you a heat-resisting equipment problem?

If so, investigate this 80 nickel, 14 chromium alloy. Inconel resists most severe high temperature conditions. It's readily fabricated and welded for construction into most types of heat-treating equipment and high-temperature furnace parts . . . and Inconel is available at comparable cost in all standard mill forms.

Our engineers are ready to discuss your special needs. There is no obligation. Write today.

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THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y.

Inconel brazing trays, each loaded with 54 Aer-A-Sol "bomb" cylinders about to enter brazing furnace.

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Now you can give EXTRA protection to your thermocouples.

Inconel protection tubes are strong, tough, and corrosion resistant. They show good strength at elevated temperatures. You can use seamless Inconel tubes up to 2200°F. in sulfur-free atmospheres. Your regular supplier has them in all sizes and lengths.

INCONEL* *(80 NICKEL - 14 CHROMIUM)* ***...for long life at brazing temperatures***

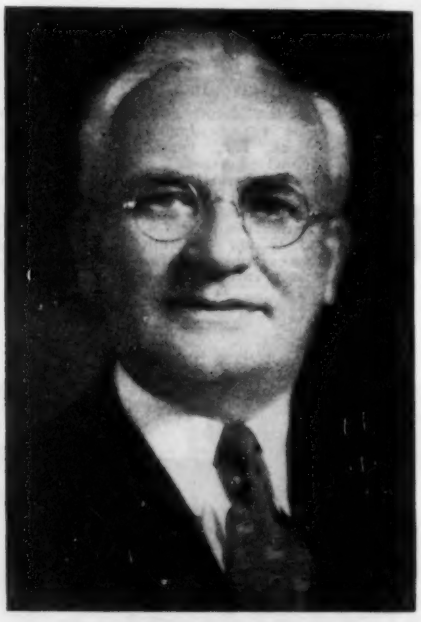
EMBLEM OF SERVICE
NICKEL INCO ALLOYS

lications, Prof. Schaller has won the Junior Prize of the ASME. During the late war, he served as consultant for several Seattle and Tacoma companies in both welding and foundry capacities.

OUR NEW DIRECTORS

David Arnott

Mr. Arnott, who has served the AMERICAN WELDING SOCIETY as its Second Vice-President, First Vice-President and President, has been elected Director for a 3-yr. term.



David Arnott

Mr. Arnott has been active in the SOCIETY since its early days, particularly in its technical activities relating to ship welding. He has delivered a number of papers before the various Sections of the SOCIETY and was author of an important chapter of the first edition of *Welding Handbook*. Mr. Arnott served as Chairman of the Committee preparing the Chapter of the 1942 edition of the *Handbook* on Ships. David Arnott has been a strong supporter of the research activities of the SOCIETY and was Chairman of the A.W.S. Committee on Welding in Marine Construction.

Mr. Arnott was born in Glasgow, Scotland, in 1878. He is a graduate of the Royal Technical College, Glasgow, and received his apprentice training in ship construction with the Fairfield Shipbuilding & Eng. Co., Ltd., Glasgow. He served as Surveyor, British Corporation Register of Shipping and Aircraft from 1901 to 1917, at its head office in Glasgow. He was also Principal Surveyor for Canada, British Corporation Register of Shipping and Aircraft, from 1917 to 1918, stationed at Toronto. Later he became Deputy Chief Surveyor, American Bureau of Shipping, from 1918 to 1925, New York. In 1925 he became Chief Surveyor of the American Bureau of Shipping, a position which he held until his retirement August 1, 1947. To these duties were added those of Vice-President of the American Bureau of Shipping in 1938. He still serves as a Consultant to the Bureau.

His technical society affiliations are quite numerous and include: Council Member, Society of Naval Architects & Marine Engineers; Member, Institution of Naval Architects; Member, British Institute of Welding; Technical Adviser to U. S. Delegation, International Safety of Life at Sea Convention 1929; U. S. Delegate to International Load Line Convention 1930. Mr. Arnott became a naturalized citizen of the U.S.A. in 1924.

The Miller Medal was awarded to Mr. Arnott in 1941 for conspicuous contributions to the art and science of marine welding.

In 1927 the American Bureau of Shipping made possible full classification for all-welded vessels, the first classification society in the world to do so.

Thomas M. Jackson

Thomas M. Jackson was born in Kennett Square, Pa. He graduated from Cornell University in 1908 with the degree of M.E. (special in E.E.). He is a member of the Society of Naval Architects and Marine Engineers and of the AMERICAN WELDING SOCIETY.

Following graduation from college he was associated for two years with the United Gas Improvement Co., Philadelphia, then for several years with Westinghouse Electric & Mfg. Co., principally as sales engineer. In 1918 he became associated with Sun Shipbuilding & Dry Dock Co., Chester, Pa., as chief electrical engineer

Thomas M. Jackson

and was also made head of the then infant Welding Department. From 1920 to date he has been chief electrical and welding engineer.

During that period he has been in charge of all welding development in ship construction and pressure vessels including design, procedure control and training. He has served on several committees of A.W.S. and is now a member of the Marine Committee. He is a member of the Pressure Vessel Research Committee, both Materials and Fabrication Division. He was chairman of the committee which prepared the chapter on Submerged Melt Welding for the 1942 *Handbook* and is chairman of the committee now preparing a similar chapter for the new handbook.

Mr. Jackson has served on the Executive Committee of Philadelphia Section A.W.S. for many years and as chairman 1937–38.

C. I. MacGuffie

Mr. C. I. MacGuffie, a native of West Pittston, Pa., was graduated from Pennsylvania State College in 1925 with a degree of B.S. in electrical engineering. He immediately became associated with General Electric in its Testing Department at Schenectady, going to the com-

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BRASS *Handled*

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Can be demonstrated in operation.
Operators can be trained in our plant to operate this equipment.
Two of the most modern and efficient production lines in the Industry for extruding shielded arc electrodes.
We urgently need the floor space occupied by this equipment for new developments.
This equipment will be sold as is, where is, at prices way below present replacement costs.
We will dismantle and load equipment on cars.
Packing for export to be paid by purchaser.

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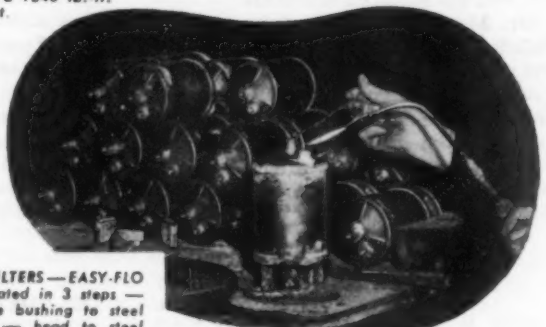
SIL-FOS EASY-FLO STARS OF AN *Amazing* INDUSTRY-WIDE "METAL JOINING SHOW"

If the hundreds of products now made with the low-temperature silver brazing alloys, EASY-FLO and SIL-FOS were assembled in one place, you would see a truly amazing display — amazing in its range and variety — but most amazing in the *extent to which EASY-FLO and SIL-FOS brazing boosted production and slashed costs* in practically every case.

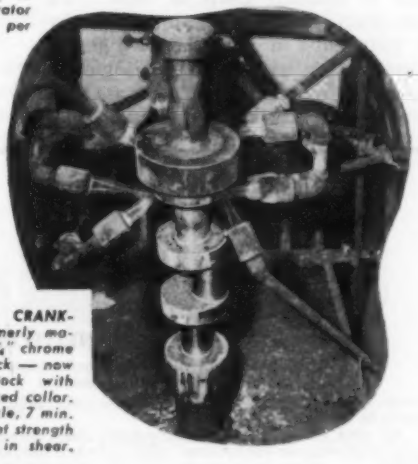
What's more, you would find nothing sacrificed in getting these results. On the contrary, product improvement is the rule — first, because EASY-FLO and SIL-FOS brazing makes assemblies that *equal or exceed the solid metal in strength, leak-tightness and all other essential properties* — and secondly, because EASY-FLO and SIL-FOS brazing *permits streamlined designs which can be produced with big-scale savings in man-hours, machine-hours and metals.*

INVESTIGATE this proven way to raise production and cut costs. Find out where and how it fits into your production. We'll be glad to send a field engineer to help you get the answer. Send for *BULLETINS 12-A and 15.* They'll give you full EASY-FLO and SIL-FOS facts. Write for them today.

UNIVERSAL JOINT — forged yoke EASY-FLO brazed to steel sleeve with induction heating — One operator does 655 per 8 hours — Every joint gets a 1540 lb.-ft. torque test.



OIL FILTERS — EASY-FLO fabricated in 3 steps — bronze bushing to steel head — head to steel shell — steel ring to shell — Each operator averages 110 units per 8 hours.



PUNCH PRESS CRANKSHAFT — Formerly machined from 5¾" chrome nickel steel stock — now from 4½" stock with EASY-FLO brazed collar. Gas brazing cycle, 7 min. 35 secs. — Joint strength rated 92 tons in shear.

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Universal Joints
Washing Machines

C. I. MacGuffie

John B. Tinnon

pany's Philadelphia office in 1928 to handle Welding Sales. In 1929 he was made welding specialist of the Atlantic District and left Philadelphia for Schenectady in 1939 to become assistant to L. D. Meeker then manager of sales of the electric welding section.

In February 1941 Mr. MacGuffie was appointed manager of sales, Electric Welding Division of the General Electric Co., which position he now holds.

Mr. MacGuffie is a past chairman of the Philadelphia Section of the AMERICAN WELDING SOCIETY, and has served on several A.W.S. committees. He is now a member of the Schenectady Section of this Society and member of the A.I.E.E. He is a member of the Publications & Manufacturers Committees of the AMERICAN WELDING SOCIETY.

J. B. Tinnon

John B. Tinnon is Vice-President of Metal & Thermit Corp. of New York. Upon completing his education at Vanderbilt University in the class of 1908, he became associated with the Chicago Surface Lines in Chicago, Ill., as assistant engineer, and in 1912 became engineer of maintenance of way and later chief engineer of the Chicago & Joliet Electric Railway Co. In 1924 he became associated with Metal & Thermit Corp as manager of their Rail Welding Department, later becoming sales manager and now Vice-President.

Mr. Tinnon has been active for many years in the AMERICAN WELDING SOCIETY and is now chairman of the Manufacturers Committee. He also has been very active for many years in the American Transit Association, having been a member of many of their committees having to do with track work and welding, and headed the Manufacturers Advisory Committee of that association. He also is a member of the American Railway Engineering Association and a number of other similar organizations.

THE METHOD OF OPERATION OF WELDING RESEARCH COUNCIL

The solution of complex, fundamental research problems is usually so difficult that it requires the combined wisdom and talent of many scientists. Certain types of research involve many branches of science and engineering, and welding is one of them. Such problems are often beyond the justifiable means of any individual corporation both as to talent and funds.

The solution of such complicated problems does not ordinarily lead to early patentable discoveries. Once the problem is stated, however, it is often so important that, were the Welding Research Council not in existence, some other means would be created for directing the work. Because the Council represents industry in general, an opportunity is created to distribute the cost of such major research among a relatively large number of companies.

Selecting Problems

It becomes necessary, therefore, in the successful operation of an organization such as the Welding Research Council, to develop simple yardsticks for measuring problems offered for consideration. The following are merely indicative as no hard and fast rules can be drawn which would be applicable in all cases.

1. The problem must be of general interest to industry at large, rather than to only a small section thereof.
2. The prospect of solution must be good.
3. The necessary funds, talent and research facilities must be securable.
4. The problem must not have been previously solved.

There are several corollary yardsticks but inasmuch as it is not intended to make this simple statement a comprehensive treatment of the subject of cooperative research, the above suggestions will suffice to point the way. Moreover careful consideration will make it fairly obvious that no single individual, or even a few individuals, would have the breadth of training and experience, or the time, to be able to apply these criteria to all of the problems presented to the Council.

At this point it might be well to trace the path of progress of one of these problems.

The problem is carefully considered regardless of its origin. The origin may be a company, an individual, a technical committee, a governmental department, or even someone outside of the country.

If the Council has a project committee working in the same general field, or in a

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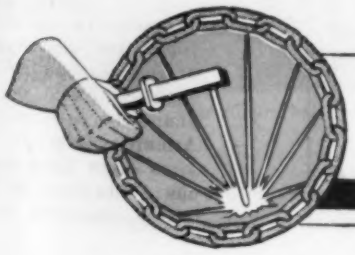

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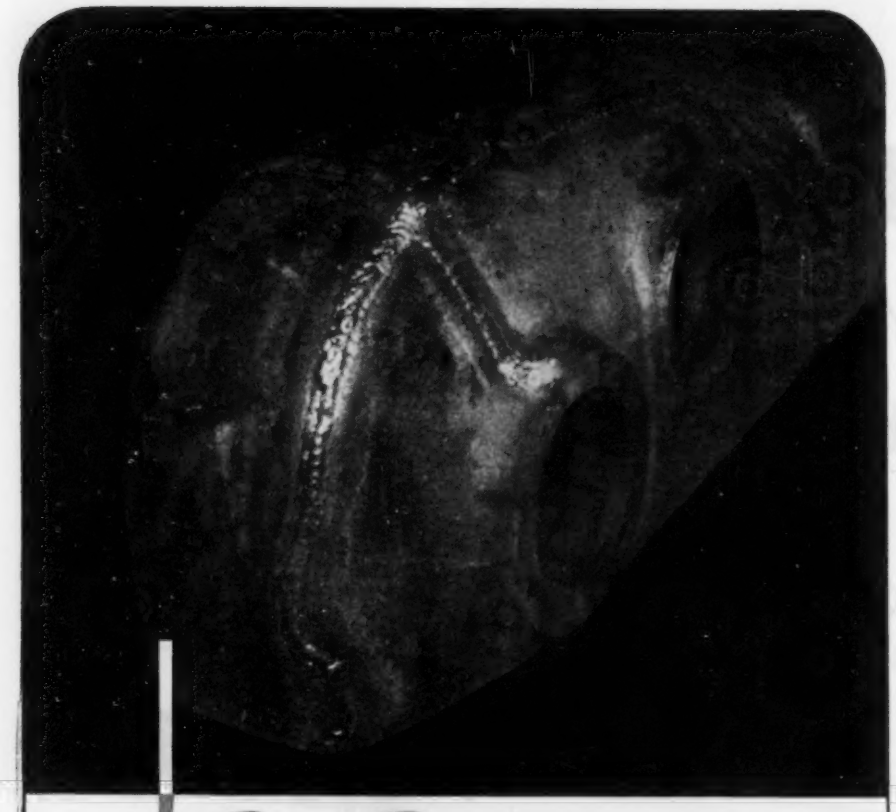

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One of the breaks passed through a machined flange. But the fact that Ampco-Trode 10 provided a machineable deposit as well as good strength and ductility solved this problem.

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closely allied field, the problem is first referred by the Central Office to this Committee for preliminary study and advice. Sometimes it is necessary to refer the problem to more than one committee.

The disposition then depends on the application of the above-mentioned yardsticks by the committee, or committees. The Central Office is informed and in turn informs the individual or other source of the problem. Very often the suggested disposition is satisfactory to all concerned, but not always. For example, a project committee may agree that the problem is important, but that it has a low priority rating in so far as the particular committee's operations are concerned. In such cases the problem is referred to the University Research Committee whose job it is to stimulate research in the universities.

It would take too long here to describe the operations of the University Research Committee—literature is available on the subject. Briefly stated the task is to find some university that is sufficiently interested and competent to undertake the problem, wih or without the advice of the project committee first mentioned. Sometimes, but not very often, the problem requires the setting up of a new project committee, and in such case there is required a fairly long and comprehensive study of the subject under the direction of the Council itself.

The application of the above-mentioned yardsticks is sometimes a difficult matter. This is well illustrated by the application of the last-mentioned yardstick. To ascertain what has already been done in a specific field sometimes requires a comprehensive digest of the literature by a thoroughly competent person, which in itself may be a serious undertaking. It may be mentioned in passing that every two years the University Research Committee compiles a list of problems that need solution. This list is periodically distributed to all of the leading universities of this country.

The Council

The Council itself is composed of some 20 leading executives interested in research. They are selected because their position and standing lend weight to the Council and assit in the financing of the work of the Council. Actual appointments are made by Engineering Foundation for a three-year term. Changes in the make-up of the Council are made to keep the group active and of sufficient standing to maintain the prestige of the Council.

In order to free itself of a mass of detail involved in the operation of a *project* of considerable size, the Council, after years of experience, has formulated certain policies and procedures of which the following are merely indicative:

1. It appoints a competent project committee representative both of the branches of science and engineering involved, and of the financial contributors. If the AMERICAN WELDING SOCIETY or some other Engineering Society has a Standard or Code Committee operating in the field

Arbor Press of Welded Design Is Stronger, Lighter, More Economical

By K. A. Ruger, President
Ruger Equipment Co., Inc., Cleveland 14, Ohio

FOLLOWING the modern trend in machine design, the new Ruger 10-ton portable hydraulic arbor press was designed for arc welded steel construction for two reasons: (1) because we have found arc welding is generally the most economical fabricating process; (2) to achieve the greatest strength from the least weight. The Ruger press can easily be moved from place to place by one man as the total weight is only about 100 lbs.

Fig. 1 shows the component parts. The plates are SAE 1020 mild steel, cut out on a flame-cutting machine guided by templates. The two side plates are braked to a 1⅛″ offset so they are closer together at the top. The base angles are formed from ⅜″ flat plate on a brake and the corners rounded on the flame-cutter. The cylinder cover is seamless steel tubing bored out to take the hydraulic cylinder.

The sides, angles, spacer plate and cylinder cover are assembled in a jig and tack-welded together. Nearly all welding is done in this jig, which is tilted to various positions for 100% downhand welding. Fig. 2 shows the cylinder cover being welded to the side plates.

Maximum welding speed is obtained by using Lincoln "Fleetwelding" technique—single pass, deep penetration welds in downhand position. "Fleetweld 11" electrode is used because of its speed, penetration and smooth concave bead which requires little finishing.

The side plates are welded to the base angles with the jig at a 45° angle (Fig. 3) to make single-pass fillets. The spacer plate is welded to sides with 1″ intermittent welds and the ends of the base angles are butt-welded to the sides. The press is

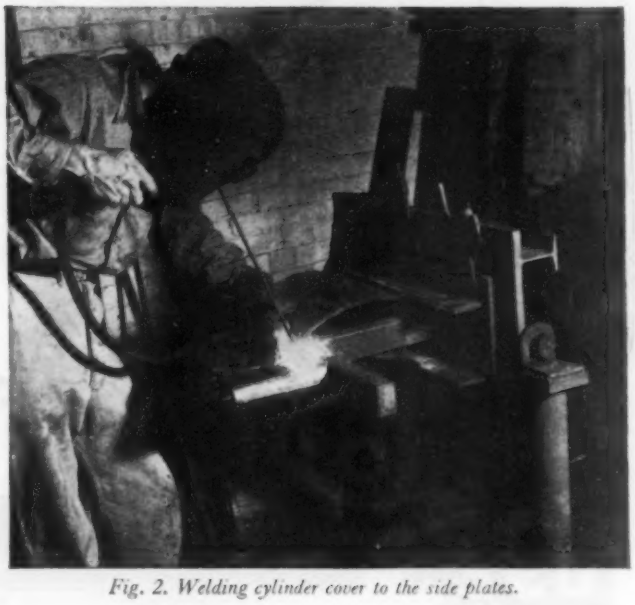

Fig. 2. Welding cylinder cover to the side plates.

then removed from the jig, turned upside down and the angles joined to bottoms of the side plates with deep groove butt welds.

The cylinder welds are then ground down flush with the sides, and the other welds cleaned with a grinder. The hydraulic pump assembly is installed and a 16-gauge sheet metal cylinder cap is welded on with "Fleetweld 7," which makes a convex bead for a neat, rounded appearance. Then the unit is painted and crated.

Fig. 4 shows the completed press. Its overall dimensions are: 23½″ high, 11¼″ wide and 20″ long from front to back. The throat height is 11″ and ram stroke is 6⅝″. Ram automatically retracts to top position by a built-in counter balance.

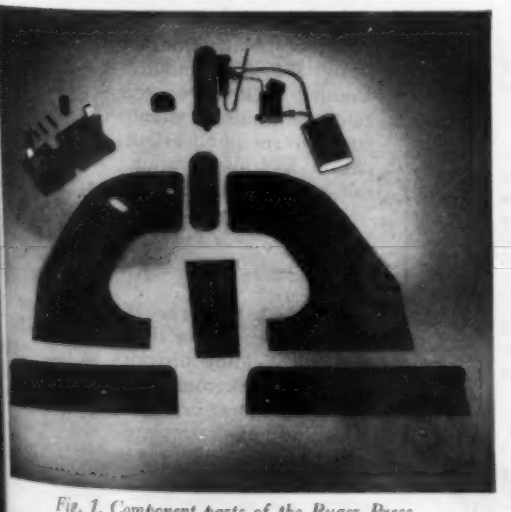

Fig. 1. Component parts of the Ruger Press.

Fig. 3. Welding base angles to side plates.

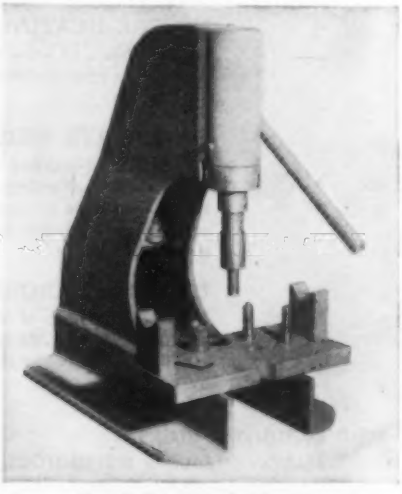

Fig. 4. The completed press.

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adequate representation is also secured from this group.

2. It encourages Project Committees to make a critical survey of the literature, or by other methods to secure an adequate knowledge of what has already been done in the field, and particularly by the most authoritative workers.
3. It requires the Project Committees to prepare careful annual Programs and budgets.
4. It requires quarterly progress reports including financial statements.
5. It encourages publication of results by the research workers, and, if advisable, also the preparation of supplementary interpretative reports by the Committee.

Briefly summarized, the Council appoints a representative competent project committee, delegates its authority to the committee and requires a reasonable accounting of stewardship.

After several years of operation, in one way or another, it often becomes obvious to the Project Committee that some reorganization, change in direction of activities or wind-up of its work is necessary. The Council seeks the recommendation of the Committee as to its future, which is very often supplemented by the opinions or wishes of the principal contributing interests.

Raising of Funds

Experience has indicated that less than 20% of the funds needed by the Council can be secured unearmarked. This leaves more than 80% of the funds contributed for specific projects and in most cases for definite programs and specific laboratories. The 20% of unearmarked funds must be sufficient to cover the operations of the University Research Committee, the Literature Committee and several other Committees which do not have large budgets warranting special efforts for separate financing. These committees of course control their own expenditures once the funds are assigned.

Out of the unearmarked 20% this leaves some $35,000 annually for which the Council itself must assume the responsibility of administration. This $35,000 in turn covers publications, records, duplication and distribution of reports, administrative salaries, rent, etc.

Advantages of Affiliation with Engineering Foundation

The fact that the Welding Research Council is successor to the American Bureau of Welding provides an interesting historical background which explains why the Council was organized under the Engineering Foundation and the advantages of such affiliation.

When the AMERICAN WELDING SOCIETY was organized in 1919 as an outgrowth of the Welding Committee of the Emergency Fleet Corp. of World War I, it was natural to make research a part of its activities, and for that purpose a body known as the American Bureau of Weld-

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...the Bond is Permanent

All known types of bond strength tests on Lukens Stainless-Clad Steels add up to this: bond strength equals or exceeds that of the steel backing plate. The results of one such type of test—a standard ASTM-ASME shear strength test made at the bond line on stock plates taken at random—are tabulated below.

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316	½"	20	46,400	52,600
316	¾"	10	40,700	55,900
347	½"	10	44,400	48,000
410	1"	10	42,200	47,300

*ASME specified minimum shear strength of clad steel bond is 20,000 psi.

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Nickel-Clad Stainless-Clad
Inconel-Clad Monel-Clad
STEELS

SOLID METAL ADVANTAGES WITH CLAD STEEL ECONOMY

ing was organized as the research department of the SOCIETY. As it proved very difficult to obtain the necessary financial and other support, after one year the Bureau was reorganized as the Joint Advisory Bureau on Welding Research and Standardization of the AMERICAN WELDING SOCIETY and The Engineering Division of the National Research Council. To meet some of the objections of the first year of operation, other interested technical and scientific societies were invited to appoint official representatives on the Bureau. The Bureau under this new setup was fairly successful, but in all probability its greatest achievements were such by-products as:

1. The demonstration of the advantages of cooperative research;
2. The establishment of research centers and the training of young men in welding research;
3. The demonstration of the relative effectiveness of scientific research as contrasted with "cut and try" methods.

In 1926 the standardization activities of the Bureau were taken over by the AMERICAN WELDING SOCIETY. In 1933 because of a serious loss in income, the National Research Council asked the SOCIETY to assume sole responsibility for administering the affairs of the Bureau. Unfortunately, the SOCIETY, because of the limitations which have been set forth in other documents, failed to operate the Bureau successfully and, in 1935, joined with the A.I.E.E. in organizing Welding Research Council under Engineering Foundation.

Engineering Foundation was established by the Civil, Electrical, Mining and Mechanical Engineering Societies for the conduct of cooperative research, and Welding Research Council was successful from the very outset as indicated by the growth of its annual budget from $5000, representing a contribution of Engineering Foundation, to over two hundred thousand dollars.

Welding cuts horizontally across the entire metal working industry. The problems created by welding are, because of their applications, of interest to nearly all branches of engineering. These branches are represented by Engineering Societies. These organizations could, of course, undertake to do their own welding research, but there would be a waste of time, talent, research facilities and money, as most of these problems involve a common background of science. The parentage of Engineering Foundation provides a ready mechanism for bringing together these groups, along with the trade associations that permit the financial backing of these industries. The Council is now sponsored by the AMERICAN WELDING SOCIETY, American Institute of Electrical Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers, American Society of Mechanical Engineers and the Society of Naval Architects and Marine Engineers.

Research projects are set up in such a way that these Engineering Societies and Trade Associations can look upon specific project committees as in effect their welding research committees.

All these arrangements serve the interests of the AMERICAN WELDING SOCIETY to a remarkable degree. It would take too much time and space to cover this point of view adequately. In outline form the continuing of the independent setup of the Council offers the AMERICAN WELDING SOCIETY the following advantages:

1. It facilitates the financing of many important research projects in welding and allied fields, which the SOCIETY alone would find it difficult to finance.
2. It facilitates the cooperation of Scientists, Universities, Engineering Societies, Trade Associations, Governmental Departments and similar bodies abroad.
3. It assists in the Educational Program of the SOCIETY aimed at other Engineering Societies and Engineers, and promotes the economic and safe use of welding.
4. It assists in the promulgation of suitable codes in fields where the AMERICAN WELDING SOCIETY does not and could not have the sole responsibility.
5. It prevents unnecessary duplication and increases the chances of the successful solution of complex problems involving many branches of science and industry.
6. It enhances the prestige of the SOCIETY and the Welding Industry, which is the ultimate recipient of the benefits of all of this research work.
7. Finally it is a *cooperative* research organization, and its success is unquestionably due in large part to its broad cooperative setup.

MORROUGH P. O'BRIEN JOINS AIR REDUCTION ENGINEERING STAFF

Morrough P. O'Brien, former dean of engineering of the University of California, has joined the engineering staff of Air Reduction Co., Inc., according to a recent announcement by C. S. Munson, President.

Mr. O'Brien will be in charge of general and process engineering and, on October 1st, will assume the direction of liquefaction research.

Mr. O'Brien is a graduate of Massachusetts Institute of Technology and the author of numerous works on engineering subjects. During the war he participated in the design of the electro-magnetic plant at Oak Ridge, was a consultant to the Bureau of Ships on problems of underwater sound, landing craft design and amphibious landings. He also served as consultant to Joint Task Force on Operation Crossroads which culminated in the atom bomb tests at Bikini Atoll.

CATALOG ON ACCIDENT-PREVENTION EQUIPMENT

The 86-page illustrated Catalog No. 50 is a veritable Encyclopedia of information on Industrial Safety and Accident-Prevention equipment—it tells what kind of Gardwell safety clothing or equipment to use to meet a specific accident-prevention need. Describes and illustrates hundreds of safety items—Gardwell asbestos, leather and rubber gloves and mittens—asbestos, leather, fireproofed duck, plastic and synthetic impregnated duck clothing—pants, coats, jackets, overalls, aprons, sleeves, hats, leggings, etc. Also helmets, hoods, faceshields, belts, shoes, grinding shields, machine guards, acid-handling equipment and hundreds of other Gardwell items too numerous to mention here. Write The Safety Clothing and Equipment Co., 7016 Euclid Ave., Cleveland 3, Ohio.

STRESS ANALYSIS MEETING

The Annual Meeting of the Society for Experimental Stress Analysis will be held at The Hotel Pennsylvania, New York, N. Y., on December 4, 5, 6, 1947.

Inquiries should be addressed to the Society for Experimental Stress Analysis, P. O. Box 168, Cambridge 39, Mass.

COMPRESSED AIR HANDBOOK PUBLISHED BY COMPRESSED AIR AND GAS INSTITUTE

Compressed Air Handbook, first edition published by Compressed Air and Gas Institute, New York, N. Y., 400 pages, 6 × 9 in., 247 illustrations, including photos and drawings; stiff-backed, simulated leather cover, gold embossed; price, postpaid, anywhere in United States, $3.00 per copy; elsewhere $3.50.

Compressed Air Handbook is published to meet widespread demands for a reference text on applications, installation, operation and maintenance of compressing equipment and air-powered tools of all types. In addition to making available a mass of new and original data not heretofore published in a single volume, the handbook contains, in revised and improved form, all of the standard reference material formerly published as "Trade Standards." Included are definitions, test standards and numerous basic tables and formulas.

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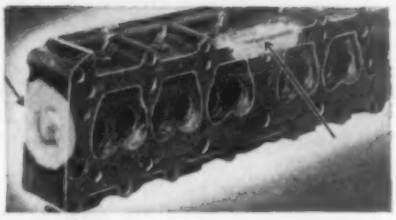

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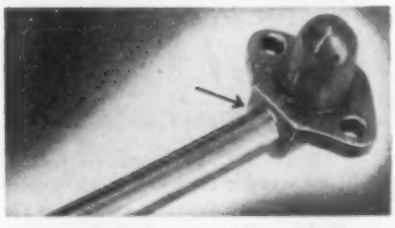

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Does everything bronze welding can do and *more!* Tougher, easier to apply and lower bonding.

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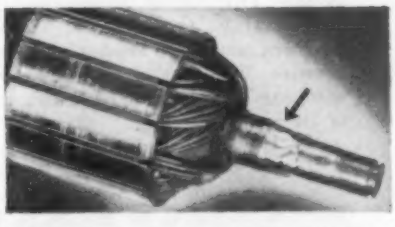
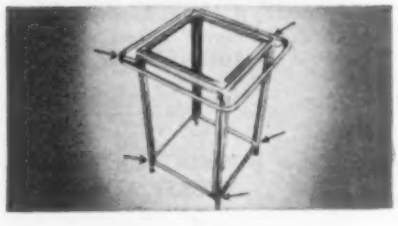


EutecRod 190 F-C

FOR ALUMINUM SHEET AND TUBING 950°F

Low melting alloy makes aluminum welding a cinch. Smooth joints, perfect color matching, good corrosion resistance. Extremely fast, easy to apply.

Also EUTECROD 21 F-C for Aluminum shapes, tubes, butt joints. EUTECROD 210 F-C for cast Aluminum. 950°—1050° F. High tensile, easily applied.



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AMERICAN STANDARDS

An entire new listing of its 874 standards is now available free of charge at the American Standards Association and may be obtained from their office, 70 East 45th St., New York 17, N. Y., P. G. Agnew vice-president of the American Standards Association announced recently.

The new listing of American Standards includes prices which are revised slightly upward, because of increased production cost, Dr. Agnew said.

A number of additional revised standards approved since the January 1947 issue of all American Standards are included.

Under the new price listing a complete set of all American Standards comes to $200 and a complete set of all American Safety Standards costs $32.50.

Customary quantity discounts are allowed in the new catalog. These range from 20 to 45% for various quantities up to 1000.

The foreword to the catalog says: "These standards are used throughout industry and by municipal, state and federal governments. Manufacturers use them to facilitate production operations or lower production costs, or to eliminate controversies between buyer and seller, or to raise the level of their industry by eliminating misrepresentation—consumer groups, as a yardstick to measure the merit of the things they buy—government agencies, in their capacity as buyers or as protectors of the public interest."

GIESEY PROMOTED

Boyd V. Giesey, formerly Senior Design Engineer for Taylor-Winfield Corp. and for the last two years in charge of the Flash Welder Division of Progressive Welder Co., 3050 E. Outer Drive, Detroit 12, has been named to head all sales of Progressive Welder Co. resistance welding equipment in the state of Michigan north of Detroit.

Mr. Giesey is opening new offices at 320 S. Larch St., Lansing, Mich., telephone, Lansing 4-9516. He will be assisted in the new operation by Robert O. Wight, formerly Welding Applications Engineer for Progressive Welder Co. He is a member of the AMERICAN WELDING SOCIETY.

NEW BOOKLET ON WELDING OF NICKEL ALLOYS

A new 16-page booklet on the materials required for the metal-arc, oxyacetylene and submerged meltwelding of nickel and the high-nickel alloys has been published by The International Nickel Co. Also, it lists such general information as the type of welding rods to use, recommended amperages for electric-arc welding, and the proper flux to select for gas welding and brazing. Information also is included on technical booklets on the subject of welding of the high-nickel alloys and sources of supply for electrodes and gas-welding wire. It is being distributed without charge.

BUILT-UP BENDING DIE COSTS LESS, LASTS LONGER

By "laminated" fabrication of the larger element of this two-operation bending die, Lincoln Electric Co. engineers have doubled its life while cutting its production cost by 60%.

The bending die, used on a 500-ton press built by The Hydraulic Press Manufacturing Co., Mount Gilead, Ohio, bends the ends of strips of $^{11}/_{16}$-in. plate, then closes the strip into ring form for welding as exciter frames.

The cylindrical die element used for closing was conventionally machined from toolsteel, while the larger bending element was built up by welding together a number of 1-in. plate sections which had been flame cut to contour to produce both male and female halves in a single operation. Wear points were protected with Lincoln A.-C. Abrasoweld to complete operations on the long-life, low-cost die members.

Actual production has proved the superiority of the laminated construction over the conventionally produced element, for this type of bending and forming. The wear-resistant welded surface has permitted the handling of stock with exceptionally rough and heavy scale, as well.

FRACTURING OF METALS

A seminar on "Fundamental Relations in the Fracturing of Metals," sponsored by the American Society for Metals and coordinated by the Case Institute of Technology, Cleveland, will be held as a special two-day technical program of the A.S.M. Annual Meeting to be held in Chicago in October of this year. Sessions will be held at the Palmer House on Saturday and Sunday, October 18th and 19th, as a part of the 29th Annual National Metal Congress and Exposition.

According to an announcement made today by W. H. Eisenman, national A.S.M. secretary, the seminar will be conducted during morning, afternoon and evening periods on both days.

"The A.S.M.," said Mr. Eisenman, "is fortunate in having the assistance of Case Institute of Technology in arranging this program. The seminar should be exceedingly valuable in contributing to the general fundamental knowledge on the subject. It is our feeling that such a first-hand exchange and discussion of view is the most efficient method of gaining a better understanding of the fundamental factors on this particularly complex subject.

"The speakers will not present papers as such, but rather will they give talks on fundamentals, based upon the large amounts of research and analysis in which each has actively engaged. Subject matter has been split up and each phase has been assigned to a speaker who is an authority in that particular field. The first choice of the speakers was made from those persons who have been concerned recently with the evaluation of results obtained in this field, rather than from those who have done particularly interesting experimental work in the field. In many cases, however, the speakers are also among the outstanding experimenters. This method of presentation should afford a complete and authoritative coverage of the over-all relations."

An analysis of the program reveals that five definite sessions have been outlined. They concern the fundamental relations involved in the fracture of metals, the fundamental factors and discussions of methods for determining and evaluating fundamental relations and factors.

On Sunday evening at 6 P.M. a dinner will be held in honor of Dr. P. W. Bridgman of Harvard University, 1947 winner of the Nobel Physics Prize. The Harvard professor will also speak at the Sunday morning meeting.

Chairmen of the five meetings include Dr. George Sachs, Case Institute of Technology, Cleveland; Dr. L. N. Donnell, Illinois Institute of Technology, Chicago; Dr. Cyril S. Smith, University of Chicago, Chicago; D. F. Windenburg, David Taylor Model Basin, Washington, D. C.; Dr. Finn Jonassen, National Research Council, Washington, D. C.; Dr. J. H. Hollomon, General Electric Co., Schenectady, N. Y.; Dr. L. E. Grinter, Illinois Institute of Technology, Chicago; Dr. Maxwell Gensamer, Pennsylvania State College, State College, Pa.; Dr. W. P. Roop, Swarthmore College, Swarthmore, Pa.; and Dr. J. E. Dorn, University of California, Berkeley, Calif.

Prominent speakers who will appear at the various meetings include Dr. Gensamer, Dr. Clarence Zener, University of Chicago; Dr. Dorn; Drs. Sachs and Hollomon; I. G. Slater, British Admiralty Delegation, Washington, D. C.; E. R. Parker, University of California; Dr. Roop; P. Shearin, University of North Carolina, Chapel Hill, N. C.; P. Symonds, Naval Research Laboratory, Washington, D. C.; Dr. Bridgman; J. Marin, Pennsylvania State College, State College, Pa.; J. D. Lubahn, General Electric Co., Schenectady, N. Y.; E. Saibel, Carnegie Institute of Technology, Pittsburgh, Pa.; E. S. Machlin, National Advisory Committee for Aeronautics, Washington, D. C.; and Dr. George Irwin, Naval Research Laboratory, Washington, D. C.

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FOR 1948

Made for Every Type of Resistance Welding Control.

The VISIBLE WAY—
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Low Maintenance • Long Life • No Variables • No Lag • No Temperamental Relays, Condensers or Resistors that Are Allergic to Weather and Temperature.

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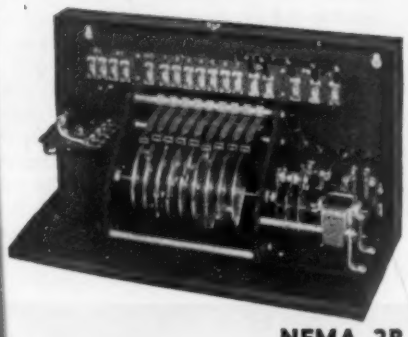
DIAL SET — Precision. Complete sequence panel for squeeze, weld, hold and off control.



NEMA 3B

With heat control, Type 1841P Duo-Trol Precision Weld-timer for aluminum and stainless steel.

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1440
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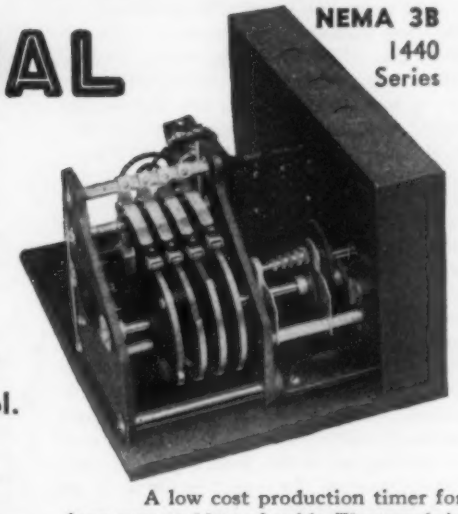
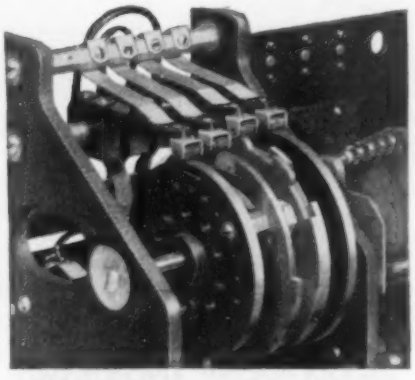


A low cost production timer for long runs and lots of welds. Thousands in use in automobile and sheet metal plants.



A **NEMA 5B** Interrupter Weld-timer, in 1540 Series. Variable "on" and "off" time.

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October 18 to 24, 1947
AT CHICAGO
See this Equipment in Operation
BOOTH No. 2435

SPECIAL NOTE: First Public Showing of
NATIONAL NEMA 1A and 1B TIMERS FOR SMALL WELDERS

NEMA 7B or 9B

1700 Series Press-weld. Non-synchronous sequence type, to control clamps, pressure, weld and off time. Also made with synchronous drive in the 1800 Series.

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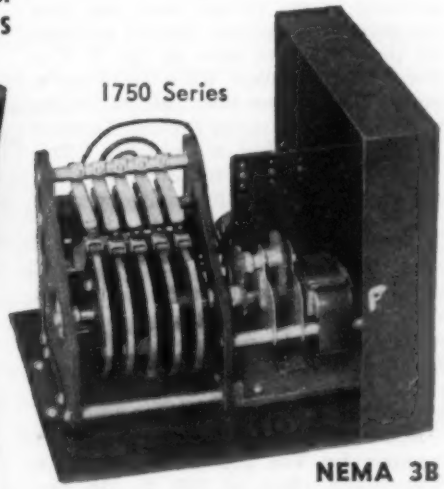

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Extensively used on welding guns at high rates of speed. Single spot, or repeat operation.

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NEW LITERATURE AVAILABLE

The current issue of the *Eutectic Welder*, published by the Eutectic Welding Alloys Corp., is now available.

The magazine is entirely given over to the new Eutectic development, "Ready-Flux-Coated" EutecRods for gas welding. These new "Ready-Flux-Coated" rods are a major advance in the gas-welding field. Because the proper amount of flux is already on the rod, the necessity for a separate fluxing operation is eliminated. The continuous presence of flux ensures instantaneous bending at the lowest possible temperature and improves the quality of the deposited metal. Not only are the physical properties improved but a tremendous saving in flux is made. This special flux coating does not require the ordinary brush fluxing, except in long lap joints, and this eliminates the slap-dash manual coating that so often in the past involved costly waste. There is no danger of running out of flux before a job is completed because the exact amount is on each individual rod. The "Ready-Flux-Coated" EutecRods reduce the amount of welding metal used and ensure a smooth, ripple-free flow.

Now "Ready-Flux-Coated" EutecRods are available for all types of metals such as cast iron, steels, brass, bronze, copper, nickel, aluminum and magnesium.

You may obtain a copy of this publication by writing to the Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

LINCOLN ELECTRIC APPOINTS TWO NEW DISTRICT MANAGERS

A. F. Boucher, welding engineer for The Lincoln Electric Co., handling special accounts in the Detroit area, has been transferred to become district manager for the Milwaukee office at 733 N. Van Buren St., Milwaukee, Wis. Mr. Boucher served in the Army from 1942 to 1945 in the Armor and Welding Section, Engineer Branch, Office Chief of Ordnance. This office was responsible for all welding and armor specifications for tanks, combat vehicles and aircraft. Mr. Boucher started with The Lincoln Electric Co. in 1936, the year he graduated from Ohio State University, and until he left to enter the service was continuously active in developing the use of welding in the Detroit field. Mr. Boucher was responsible for many of the late applications of arc welding in the automotive industry.

Marshall Ford has been made district manager for The Lincoln Electric Co.'s Minneapolis office at 529 S. 7th St., Minneapolis, Minn. Mr. Ford has been a welding engineer for The Lincoln Electric Co. since 1941 in the Pittsburgh district. He has been active in the development of welding applications in the steel and mining industries. Before coming to Lincoln he spent three years working for the Inland Steel Co. in Chicago. Mr. Ford is a graduate of Western Reserve University, class of 1938.

Both Mr. Boucher and Mr. Ford are members of The American Welding Society.

WORLD'S LARGEST MECHANICAL PRESS BRAKE

Completion of the world's largest-mechanical press brake is announced by the Warren City Manufacturing Co., Warren, Ohio, leading manufacturer of mechanical and hydraulic presses and press brakes. The first unit is being delivered to the McKeesport, Pa., plant of the Jones & Laughlin Steel Corp., whose engineers cooperated.

Of fully stress-relieved welded steel construction, the "Warco" press brake weighs in excess of 500,000 lb. without dies. The machine is designed to exert a pressure of over 1000 tons for bending to a right angle in a single stroke steel plate $^5/_8$ in. thick in lengths up to 36 ft. The brake, which makes 15 strokes per minute, has all moving parts counterbalanced by air cylinders. The machine's flywheel, weighing over 10,000 lb., and rotating at 450 rpm., is driven by a 75-hp. electric motor. This huge machine is controlled by an operator stationed at a finger-tip control electrical push button station. Setting of the ram is also electrically controlled by means of a push button control with indicators showing the exact ram setting within one-thousandths of an inch. All lubrication is centralized from one position.

Owing to the great weight and size of the unit, over 36 ft. long, 16 ft. front to back and 20 ft. high, the brake is being dismantled for shipping in five separate freight cars. The four bodies, each weighing over 50,000 lb. are being shipped in special well cars so as to provide sufficient clearance.

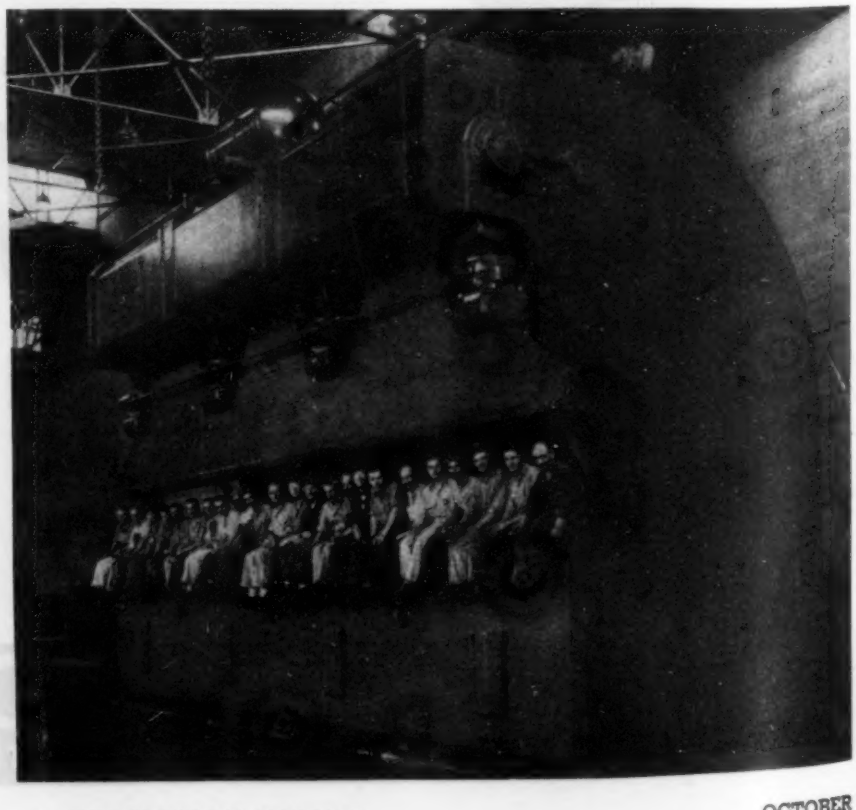
LINCOLN FOUNDATION ANNOUNCES RULES OF ANNUAL ENGINEERING UNDERGRADUATE AWARD AND SCHOLARSHIP PROGRAM

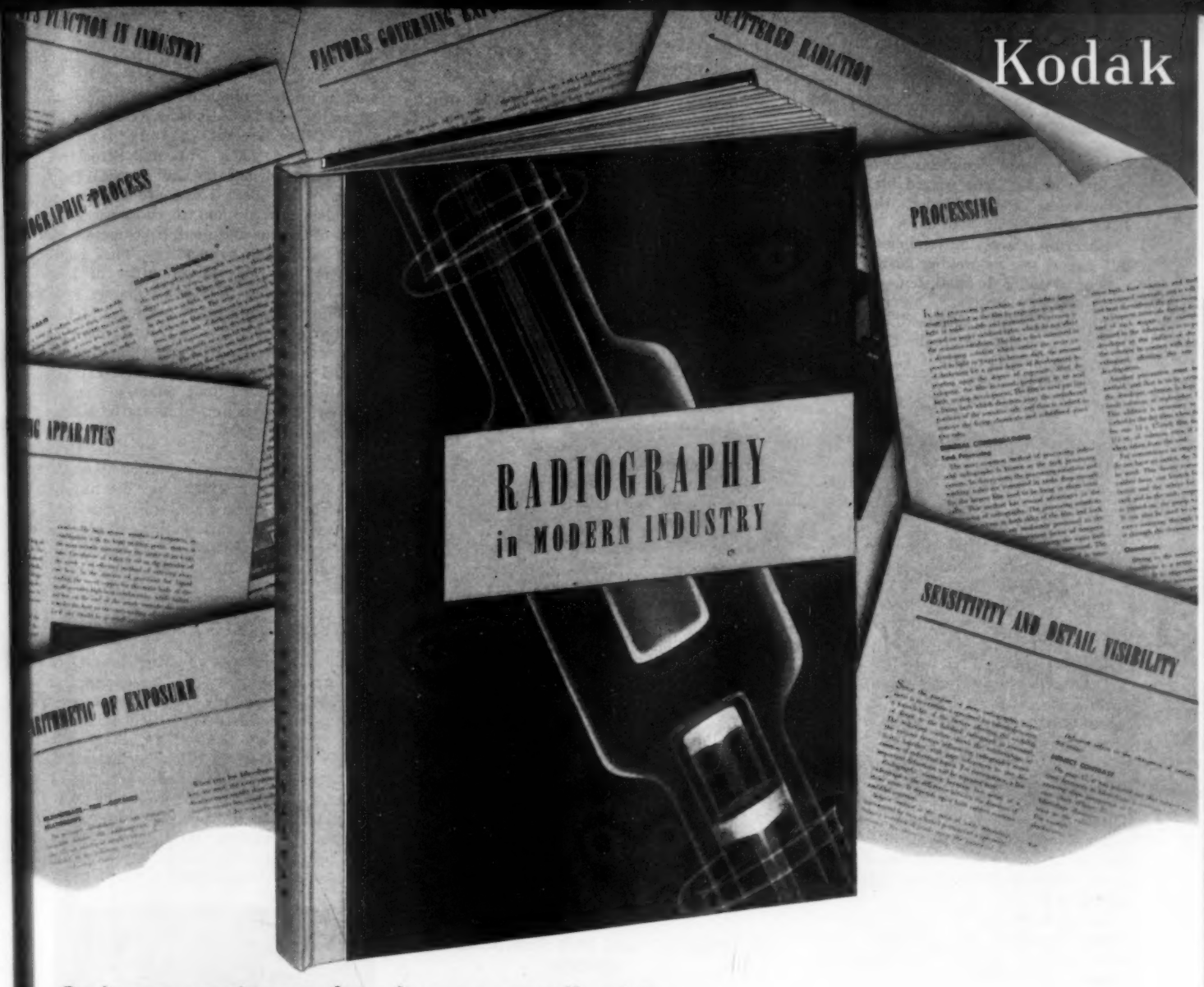
The Trustees of The James F. Lincoln Arc Welding Foundation announced today the rules of their Annual Engineering Undergraduate Award and Scholarship Program. This program started in 1942 but was interrupted by the war. Recently upon the advice of the Deans of Engineering of a number of prominent engineering schools, it was decided that the time had arrived when the program should be resumed.

Dr. E. E. Dreese, Chairman of the Board of Trustees, in making the announcement stated: "The future of engineering rests with the present undergraduate engineering students. The engineering students of today will bring forth the new inventions, designs and developments of tomorrow.

"The great contributions of arc welding to the prosecution and winning of the late war and the many ingenious and economic applications of this process to peacetime construction, mark it as such a great contribution to new engineering that the undergraduate engineering student should familiarize himself with its possibilities in the design and maintenance of machinery and structures. The oncoming students in engineering institutions will develop yet newer designs through the use of arc welding, for the advancement of engineering work throughout the world.

"In order, therefore, to place these possibilities before the undergraduate engineering student, and to stimulate his imagination, ability and vision through the study of arc welding in design and maintenance, The James F. Lincoln Arc Welding Foundation sponsors this series





Designers, engineers, foundrymen, metallurgists, quality-control men, radiographers, welders . . .

. . . here's a *NEW* book that will answer your questions about x-ray practice and technics . . . clearly, quickly, authoritatively. Price $3. Order your copy now.

BETWEEN the covers of this book is a complete, authoritative x-ray text . . . an invaluable answer book on practical x-ray questions. It gives industrial x-ray users the most up-to-date . . . the most clear-cut operating data available!

Every important phase of radiography is thoroughly discussed in its 122 pages. Data are completely backed up . . . by 64 highly illustrative photographs . . . 38 colorful drawings . . . 44 newly published, clearly presented tables and charts!

This material gives you the answers to questions like these: *How can I get higher contrast and better detail visibility in my radiographs? . . . Can I improve sensitivity by processing longer? . . . Can I increase penetration with intensifying screens? . . . Is agitation during development important?*

Here is your guide to more efficient x-ray results. Order your copy of "Radiography In Modern Industry" from your local x-ray dealer.

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Radiography . . . another important function of photography

of $6750 Annual Engineering Undergraduate Award and Scholarship Programs."

This Program contains two interdependent plans: The Award Plan and the Scholarship Plan. Under the Award Plan, engineering students of various engineering schools and colleges will submit papers on arc-welded design and the use of welding in maintenance of machines and structures. Under the Scholarship Plan, scholarships will be allocated to the schools in which the three highest award recipients under the Award Program are registered.

Awards for papers will be as follows:

Number of Awards	Amount of Each Award	Total Amount of Awards
1	$1000	$1000
1	500	500
1	250	250
4	150	600
8	100	800
12	50	600
50	25	1250
77		$5000

The Scholarship Plan is as follows:

The institutions in which the three top awards are made to students will receive amounts of money equal, respectively, to those awards. These amounts are to be used for the purpose of scholarships in the departments in which the award students are registered.

Use of Scholarship Funds: The department of the institution in which the first award winner is registered will receive $1000 for four annual scholarships of $250 each.

The department of the institution in which the second award winner is registered will receive $500 for two annual scholarships of $250 each.

The department of the institution in which the third award winner is registered will receive $250 for one annual scholarship of $250.

Number of Scholarships	Amount of Each Scholarship	Total Amount of Scholarship Funds
4	$250	$1000
2	250	500
1	250	250
7	250	$1750

Students' papers are to deal with design for arc welding of parts of machines, complete machines, trusses, girders, structural parts, or their maintenance.

It is not necessary that the machine, structure or part be actually built, but the design or method of construction must be described in the paper.

The student need not necessarily adapt arc-welded construction to a complete machine or structure but may choose any part of a complete machine or structure, now usually made by other methods, which could be made by this method of construction; or he may conceive of a machine, structure or part which has never been built but could be built by arc welding.

Resident engineering undergraduate students registered in any school, college or university in the United States, which offers a curriculum in any branch of engineering (including agricultural engineering) or architecture leading to a degree and cadets registered in the United States Military Academy, United States Naval Academy and Coast Guard Academy are eligible to submit papers in this award Program.

In rating the merits of the paper, the Jury of Award will give proper consideration to:

Ingenuity and originality displayed.
Clarity of design and description
Practicability of the conversion described
Technical completeness and thoroughness
Statement of advantages such as savings in time or money or improvements in performance and social advantages, of the construction, or design, described in the paper, over other methods
Presentation: correct use of English; quality of illustrations; neatness; succinct expression.

The Rules of the Program were reviewed and approved by the Deans of Engineering of fourteen prominent engineering colleges. Papers must be postmarked not later than midnight, May 15, 1948, and awards will be announced as soon thereafter as is practical.

Copy of the Rules and Conditions may be obtained by writing The James F. Lincoln Arc Welding Foundation, Cleveland 1, Ohio.

INGALLS ADDS NEW SUSTAINING MEMBERS

Alfred E. Pearson has been designated as the new sustaining member of the Ingalls Shipbuilding Corp. This company has its principal office in Birmingham, Ala., constructs all types of welded ocean-going and river vessels. Vessels recently completed include Luxury Liners, C-3 cargo ships, ocean-going dredges, derrick barges, towboats, oil and dry-cargo barges. One of its shipyards is located at Pascagoula, Miss., where 14 welded cargo vessels for Brazil and 4 for Argentina are under construction. The Pascagoula Yard also builds Diesel locomotives and fabricates a variety of structural steel and plate work. Another of its shipyards located at Decatur, Ala., on the Tennessee River, is building 25 self-propelled barges for the French Government and other river craft.

METALS AND PLASTICS

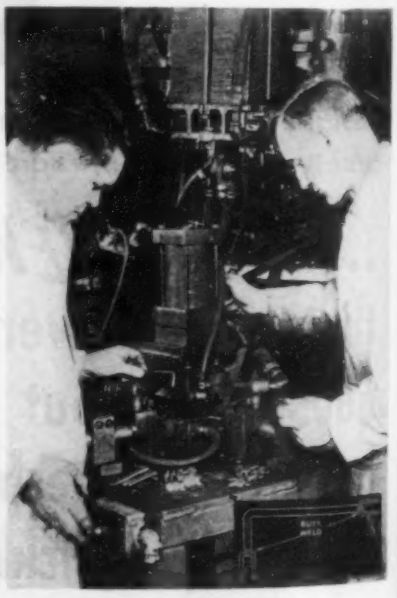
By Thomas P. Hughes. Published by Irwin-Farnham Publishing Co., 332 S. Michigan Ave., Chicago 4, Ill. Price $4.50. 373 Pages. The underlying purpose of this volume is to present a comprehensive perspective of manufacturing processes with a detailed study of some of the more common metals, alloys and plastics so that the student will have an understanding of their fundamental potentialities and a basis for selection.

The first several chapters deal with Metals and Their Internal Structures, Equilibrium Diagrams, and Physical Properties of Metals. These are designed to introduce the student to the basic structures of ferrous and nonferrous metals and alloys and their properties. Then follow chapters on The Manufacture of Iron, The Production of Steels, Casting Processes, The Mechanical Working of Metals, Nonferrous Metals and Alloys, Welding Processes, The Iron-Iron Carbide Equilibrium Diagram, and The Heat Treatment of Metals. The final chapter classifies the various steels according to the A.I.S.I. and S.A.E. systems.

The chapter on Plastics classifies these materials and discusses their composition, the processes by which they are formed, and the engineering applications and properties of the various types of plastics. Glossaries of terms used in the text are furnished in the Appendix.

WELDING PETCOCK WRENCHES

The flexibility with which resistance welding equipment can be adapted to specialized assembly problems in mass production is illustrated by a simple welding "machine" devised at Progressive Welder Co., Detroit, Mich., for assembling "universal" automotive radiator petcock wrenches. The machine was made up by converting standard portable spot-welding gun equipment to a stationary butt-welding "machine" by use of a special air clamping stationary fixture. With this a



production of 150 completed double and petcock wrenches per hour was obtained.

The wrench consists of 2 U-shaped mild steel stampings of different sizes, welded one to each end of a bent steel rod. Simple projection-welder type air-clamping dies hold the shank of the wrench. The two jaws are dropped over specially formed electrodes of two standard hydraulic push guns mounted in place. The guns move the petcock wrench jaws up to the shank under welding pressure to form the series butt weld.

PAGE *Welding* ELECTRODES

C+X=S
WHERE:
C= COMPLETE RANGE OF ELECTRODES AND GAS WELDING RODS
X= EXPERIENCED FIELD SERVICE MEN TO RECOMMEND CORRECT RODS AND TECHNIQUES
S= SAVINGS IN WELDING COSTS

This is the PAGE formula for economy in production welding. The uniformly high quality of PAGE welding electrodes and rods is not included, because that is simply taken for granted by experienced welders.

Through PAGE Field Service Men, your PAGE distributor can give you valuable up-to-date information on welding techniques and selection of electrodes. That's why we say . . .

Get in Touch with Your PAGE Distributor

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PAGE STEEL AND WIRE DIVISION
AMERICAN CHAIN & CABLE

TRADE MARK

Clamping pressure is applied by means of a standard Progressive air cylinder controlled by an air valve mounted on the cylinder support where it is convenient to the operator. Balance of the equipment consists of standard 50-kva. portable gun welding transformer, a standard air-hydraulic booster to apply welding pressure and simple weld timer, mounted on a nearby wall to control the welding cycle. Electrodes, dies, cables and transformers are all water-cooled.

The arrangement lends itself to maximum operator comfort with high productivity, an operator standing or being seated (it is just as easy either way) in front of each of the two guns. The operator at the right loads the wrench shank and one jaw, and works the air-clamp control. The operator at the left loads the other wrench jaw and initiates the welding cycle by pressing the palm switch, and unloads the completed wrench.

"DUKE" HOWLAND MADE SALES MANAGER

Metal & Thermit Corp. announces the appointment of O. L. (Duke) Howland as Sales Manager of its welding division with headquarters at 7300 S. Chicago Ave., Chicago, Ill.

Mr. Howland came with the company in 1943 as District Manager of its Chicago branch. An alumnus of the University of Wisconsin, his first job was with a surveying party of the Phelps-Dodge Corp. in Mexico. During World War I he served

O. L. (Duke) Howland

in the Merchant Marine and from there entered the welding industry as a welding specialist for Central Steel & Wire Co. of Chicago. In 1924 he went with Lincoln Electric Co. as a District Manager in Indianapolis and two years later returned to Central Steel & Wire. From 1927 to 1931 he was general manager of Koro Corp., a welding supply organization, and in 1932 joined the Hollup Corp. as Eastern Manager, returning to Chicago in 1936 as its Sales Manager. During World War II he headed the War Production Board's welding division in Washington. Mr. Howland is a member of the AMERICAN WELDING SOCIETY.

As aide to Mr. Howland, Wm. C. Cuntz has been made Assistant Sales Manager of the corporation's welding division with headquarters at 1514 W. North Ave., Pittsburgh, Pa.

"TORCH BRAZING ALUMINUM"

A 12-page reprint of an article entitled "Torch Brazing Aluminum," which originally appeared in a recent issue of *The Welding Engineer* has been announced by the Air Reduction Sales Co. Written by Harry A. Huff, Airco's brazing specialist, the article encompasses the entire field of aluminum brazing.

The article, illustrated with photographs and descriptive diagrams, covers such topics as the advantages of aluminum brazing, types of aluminum, strength and corrosion resistance, filler metals and fluxes, cleaning procedure and production torch brazing.

Copies may be obtained by writing Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y., or the Airco sales office nearest you.

$75,000 PRESSURE VESSEL RESEARCH PROGRAM

Progress in the pressure vessel research program costing $75,000 a year, which has been undertaken by the Welding Research Council of the Engineering Foundation, was reported yesterday by Dr. A. B. Kinzel, chairman of the board of the Foundation.

"The program aims at developing information and data which will lead to better, safer and more economically constructed pressure vessels," said Dr. Kinzel.

Walter Samans of the Sun Oil Co. continues as chairman of the project's general committee which is made up of 87 representatives of manufacturers and users of pressure vessels, insurance companies, educational institutions and branches of the U. S. government. The principal financial support is being provided by interested manufacturers and users of pressure vessels.

The program, which was instigated by the Welding Research Council, secured the hearty support of industry and the cooperation of several engineering societies. The studies cover four phases of the problem, design, fabrication, and testing and inspection.

Design Receives Largest Allocation

A sum of about $30,000 has been allocated this year to the study of pressure vessel design, Dr. Kinzel stated. A program of research has already started at Purdue University under the direction of Professor R. G. Sturm.

"At present formulas for the design of different type of heads, openings and supports for pressure vessels vary greatly and there is no means of knowing the precise factor of safety comprised in each," he continued. "Basic information to be assembled under the committee's direction will make it possible for designers to calculate precisely suitable thicknesses for these various parts, and for code-making bodies to modify their rules to insure pressure vessels which are both safe and economically constructed.

"Where expensive materials are being used savings may amount to hundreds of hundreds of thousands of dollars and in other instances where failures may mean loss of human life, the value of the work cannot be overestimated."

The second largest phase of the research program is the fabrication division headed by H. C. Boardman of the Chicago Bridge & Iron Co. Approximately $20,000 has been set aside this year for such studies, some of which are already under way at Lehigh University. The purpose of this division is to secure information on the effect of fabricating processes on the materials used so that code-making bodies may formulate rules for selection and procurement of steels and correctly assign values of safe design stresses without necessarily penalizing the fabricator and eventual purchaser of the pressure vessel.

The materials division is headed by D. B. Rossheim of the M. W. Kellogg Co. The chairman of the inspecting and testing division is D. L. Royer of the Ocean Accident and Guarantee Corp., Ltd. The work of these committees consists a present of a critical review of existing literature.

The central office for the Pressure Vessel Research Committee has been set up at 30 Church St., New York, where administrative work is carried on and research results correlated.

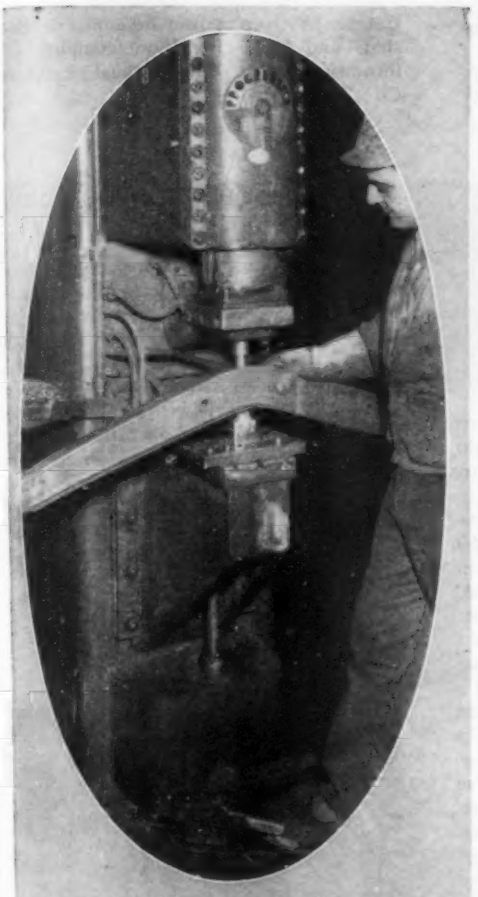
Employment Service Bulletin

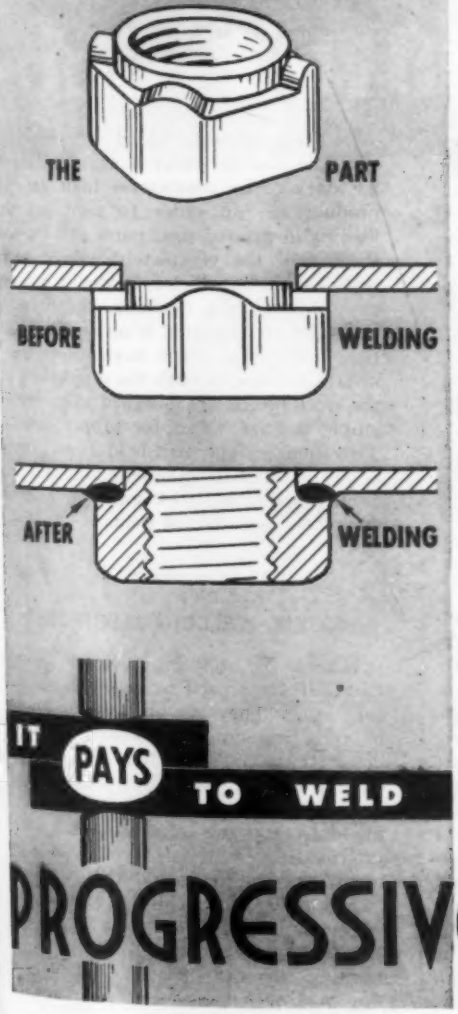
SERVICES AVAILABLE

A-552. Welding Engineer, Supervisor, and/or Instructor. Young, able and aggressive, with intelligence, personality and initiative: can furnish references to substantiate these seemingly ambitious claims. Background includes sales, practical welding experience, inspection and production testing of welding electrodes supervision and instruction of manual and automatic welding operators, drafting of statistical reports, and preparation of technical and nontechnical papers for publication. Presently employed but desirous of better position. Now located in New York metropolitan area, but will travel if necessary.

POSITION VACANT

V-213. Executive Secretary, important research committee. Applicant should have experience preferably in all three following categories: pressure vessel design, metallurgy, welding research. Salary up to $7500, depending on experience and capacity.





How to Attach a threaded nut

The simplest and best way to attach a nut is to THREAD IT FIRST and then projection weld it to the part. That's what Midland Steel Products is doing on automobile and truck frames—using a Progressive Press Welder. NO RETAPPING is necessary after welding.

Formerly either arc-welded or mechanically attached to frames, these nuts (see sketch) are placed in a die on the lower platen of the welder. The part is slid along until a registering hole drops over the shoulder on the nut. The upper platen is brought down, one shot of current is passed through the nut, fusing the projections to the side-rail and the job is finished. A dozen or more nuts are attached to the side-rail shown in this manner. Nuts range in size from ¼ to ½ inch.

If you have a problem of attaching threaded studs or nuts to other parts, consult Progressive's PROCESS ENGINEERING DEPARTMENT. We will be glad to help you.

Are you reading Progressive's Resistance Welding Pictorial? Here you will find each month case histories of how WELDINGENUITY is cutting manufacturing costs and improving product appearance, performance and life. Ask for it on your company letterhead.

Booth 1242
at the Metals Show, Chicago

CABLE ADDRESS "PROGWELD"

MEMBER RWMA RESISTANCE WELDER MANUFACTURERS ASSOCIATION

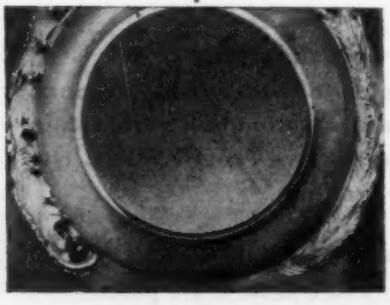
Welder Co. 3050 E. OUTER DRIVE • DETROIT 12
RESISTANCE WELDING EQUIPMENT

NEW PRODUCTS

The Society assumes no responsibility for the validity of claims in this Section

AIRCO ANNOUNCES IMPROVED NO. 312 ELECTRODE

The Air Reduction Sales Co. announced the availability of an improved Airco No. 312 electrode. Originally placed on the market 2 years ago, it is an all-position, mild steel electrode designed to produce weld metal possessing not only excellent mechanical properties, but also low hydrogen content.



The Weld at the Left Was Made with Conventional Mild Steel Electrodes. The Weld at the Right Was Made with the Improved Airco 312. Base Plate Is Cold-Rolled Steel; Central Part Is High Sulphur (0.30% S) Free Machining Steel.

According to the manufacturer, the improved Airco 312 electrode has two advantages over its predecessor:

1. It can now be used on a-c and d-c reverse polarity current. Operating characteristics are said to be equally good on either a-c or d-c reverse. The former 312 electrode could be used only on d-c reverse.

2. Preheating of the electrode is no longer required with the improved Airco 312 to obtain porosity-free weld deposits. These deposits can be obtained by using either the stringer bead or the full weave technique.

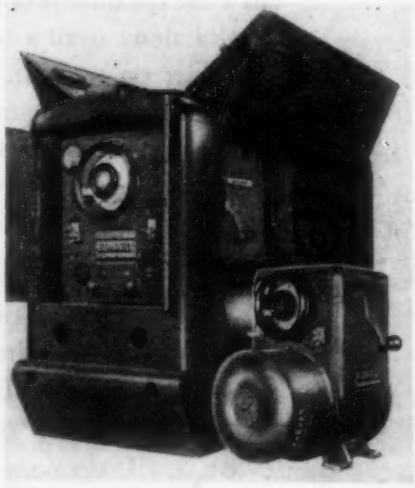
The recommended uses for the improved Airco 312 are: welding high sulphur, free machining steels; welding hardenable steels where no preheat is used; welding cold-rolled steels which normally exhibit excessive porosity when welded with conventional electrodes; weldments to be vitreous enameled after welding. The extreme low hydrogen content of the improved Airco 312 makes possible the production of satisfactorily enameled surfaces without any heat treatment prior to enameling.

For further information on the improved Airco 312 electrode write Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y., or the Airco sales office nearest you

REVOLUTIONARY TYPE OF ARC WELDER AND POWER UNIT COMBINATION

The Hobart Brothers Co., Troy, Ohio, is announcing a revolutionary type of arc welder and power unit combination.

They have developed a new full capacity 200-amp. rotary a.-c. arc welder for construction, maintenance and repair welding, which includes a simple operated change-over switch to convert the welder generator into a 52-amp., 120-v., 60-cycle, 5-kw.-hr., 6.3-kva., single-phase power unit. In this machine, you not only get a full-capacity, 200-amp., a.-c. welder, but an a.-c. power unit which will supply sufficient power to operate fifty 100-w. lamps (or their equivalent) regularly or as an emergency "standby" power source. It can also be used to operate electric drills, grinders, saws, hammers, compressors, paint sprayers and other electric motor-driven equipment.

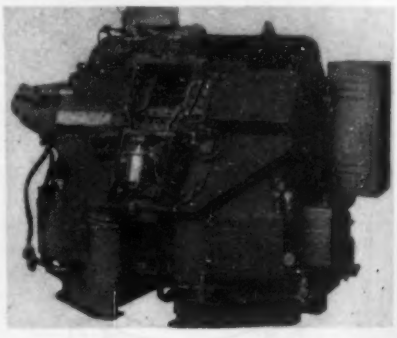


This Hobart development is surprisingly compact and light in weight, due to the ingenious manner in which a single generator, powered by a single gasoline engine, is made to do all the useful jobs this unit will do. It is the first equipment in the history of arc welding that makes it possible to use alternating current for welding without being tied down to locations where power lines are accessible. And just as important are its advantages that enable the operator to weld and use power tools alternately from the same power source.

The GA models are complete, factory-built, gasoline-engine driven units. The WA model is offered for use with your own power source, such as gasoline engine, tractor or Jeep power-take-off, or line shaft and belt. For more complete information, write The Hobart Brothers Co., Troy, Ohio.

NEW HIGH-PRODUCTION PROJECTION WELDER

A new high-production projection welder is announced by The Federal Machine and Welder Co., Warren, Ohio, a leading manufacturer of resistance welding equipment and other high-speed production machinery. The first unit has been delivered to a large Eastern typewriter manufacturer where it is in volume operation welding retaining strips and other subassemblies to the steel stampings forming the main typewriter body assembly. Using only one semiskilled operator, the machine produces approximately 200 completed assemblies per hour.



Of stress-relieved, welded steel construction, the machine ensures maximum rigidity during the continuous high rate of production. In order to facilitate the loading of pressed steel parts and the unloading of the completely welded main body assembly, which is welded in a single pass through the machine, the mandrel and head are mounted in an angular position. The dies, which have special alloy inserts to coincide with the projections on the work pieces, are designed to ensure an ample flow of water for proper cooling. Two small air-operated hold-down clamps act as an auxiliary clamping unit and precisely locate the work parts in position during the sequence of welds.

NICKEL WELDING ELECTRODES

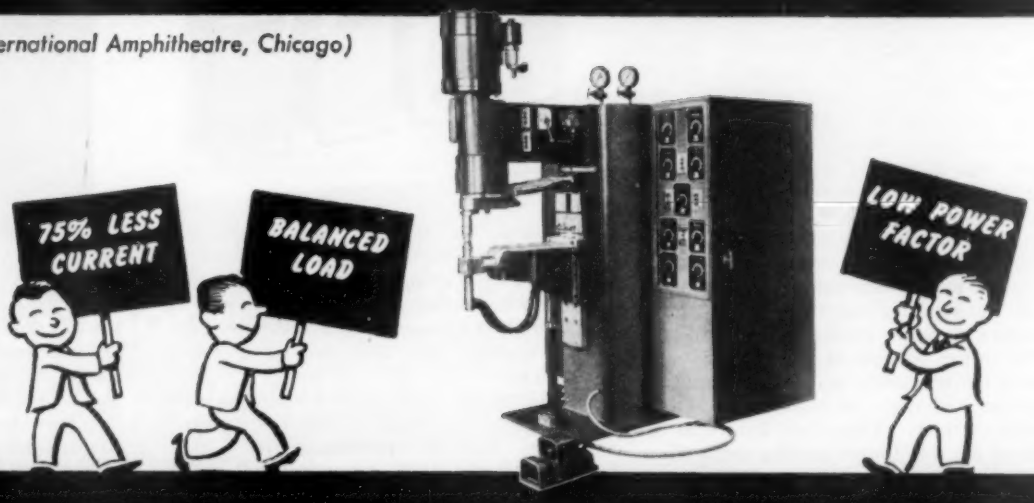
Eureka No. 100 Pure Nickel Welding Electrodes are used to weld all types of cast iron. They are outstanding for use in repairing cracked, broken, worn or defective castings and for correcting machining errors. They are excellent for repairing cast-structured drawing and forming dies, and are generally used as an intermediary material between the base metal and the final deposition of Eureka "Drawalloy" or Tool Steel Electrodes.

Eureka No. 100 Pure Nickel Welding Electrodes operate on either d.-c. or a.-c. welding currents. These electrodes produce a stable, smooth and spatter-free arc

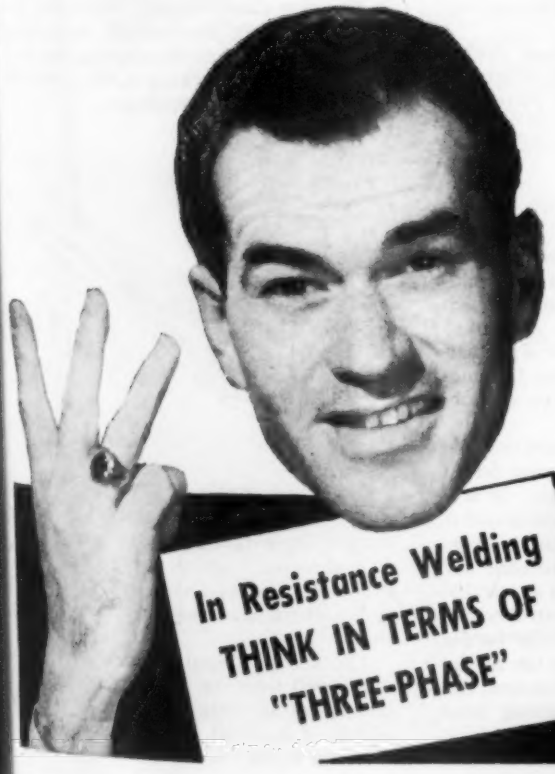
CHICAGO

Going to the Metal Show?

(October 18th—International Amphitheatre, Chicago)



see **Three-Phase*** welding!



In Resistance Welding THINK IN TERMS OF "THREE-PHASE"

You'll want to see this new achievement in *resistance welding power efficiency* in action! Drop in at our booth No. 1254 and see how "*Three-Phase*" welds aluminum, brass, and heavy gauges of steel with ¼ *the current* required by conventional single-phase machines . . . and on a balanced three-phase load at near unity power factor . . . and all this on ordinary power distribution facilities! On view also will be standard Sciaky single-phase machines, spot, seam, projection and portable.

And if you can't attend the show—find out about "Three-Phase" anyway! Just write and ask for bulletins No. 136 and 137A. Sciaky Bros., Inc., 4915 W. 67th St., Chicago 38, Ill.

Specialists in the design and manufacture of precision resistance welders. Consult us on your welding problems. There is a Sciaky office or representative near you.

***Exclusive Patented Development by**

SCIAKY

action with perfect slag coverage of weld deposits. Eureka No. 100 Pure Nickel Electrodes afford low temperature fusion with minimum penetration.

The coating on Eureka No. 100 Pure Nickel Electrodes is free of fluorides and will not produce injurious gases. The *insulating coating* also prevents arcing of the electrodes when working in confined quarters.

SILVER SOLDER

All-State Welding Alloys Co., Inc., 96 West Post Rd., White Plains, N. Y., announces the immediate availability of a new silver solder with two exceptional advantages—a shear strength of 105,000 psi. and a melting temperature of only 1076° F., the lowest known melting temperature for any silver solder. This alloy is recommended for applying high-speed tool tips that have critical temperature ranges, and is especially suitable for the fabrication and repair of equipment in the electrical and refrigeration industries. The silver content of this alloy is 40%, with the remainder made up of cadmium, copper and zinc. It is available in wire, strip or rings. This alloy, known as All-State No. 111 lowest-melting-point silver-brazing alloy, is used with All-State No. 100 flux.

SPRAYING HARD COATINGS

A new method for hard facing by using a metallizing gun and METCO-WELD H, a "wire" composed of a powdered hard-facing alloy extruded with a plastic binder, is announced by Metallizing Engineering Co., Inc., Long Island City, N. Y.

This Sprayweld method attains the previously difficult objective of applying smooth, uniform, relatively thin hard coatings, in a highly practical and inexpensive manner.

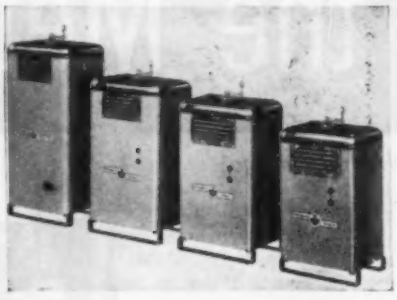
During the spraying operation, the plastic binder is completely volatilized, and the deposit consists entirely of the metallic constituent. Subsequent fusing, with any fusing torch or with an attachment on a METCO metallizing gun, results in a coating alloyed to the base and physically and chemically identical to hard facings of the same alloy applied by other methods.

The alloy used in METCO-WELD H is unique in many respects. It possesses excellent resistance to abrasion—will outwear hardened steel 3 to 10 times for this type of service. It resists corrosion better than stainless steel under most of the conditions for which stainless is generally used. It combines a low melting point with a long range of plasticity (1850 to 2050° F.). It has high strength at red heat and exceptional-resistance to oxidation.

Bulletin 53 explaining the operation and advantages of the Sprayweld process is available upon request to the Metallizing Engineering Co., Inc., Long Island City, N. Y.

LOW-VOLTAGE INDUSTRIAL WELDER

A new and smaller designed Flexarc industrial line of a.-c. welders is available from Westinghouse. A sturdy, compact, streamlined case and a well arranged interior with reactor and transformer built around high permeability Hipersil steel cores are features of the new line.



Called "The 65 Line" for the open circuit voltage, these new welders incorporate the latest engineering features assuring high arc stability in the lowest as well as the highest current ranges of the five output ratings—200, 300, 400, 500 and a duplex 300/600 amp.

Built-in low voltage control assures high operating efficiency in the low current range; built-in capacitors assure a high power factor and economical full rated operation.

Natural ventilation, movable core reactor operated by single ball crank current adjusting mechanism—a Westinghouse pioneered development in a.-c. arc welder construction—guarantee minimum maintenance and attention. To reduce overall size and maintain uniformly high operating efficiency, fan cooling is employed in the 500-amp. ratings.

Heavy duty castors for extreme portability and strap skid mounting on stationary units add to the welder serviceability.

Further information on these welders may be secured from the Westinghouse Electric Corp., P. O. Box 868, Pittsburgh 30, Pa.

WELDING TIMER

The #52D Timatron, electronic welding timer, eliminates guess work in spot welding. Uniform production is assured, which gives precision control to flow of current in timing the weld. Once set for a particular thickness of metal, timing becomes automatic throughout the entire production run.

The Timatron Timer is designed to make installation simple and inexpensive on all types of spot-welding machines. It is a simple matter for an electrician to install it in a short time, usually less than an hour. The control has the capacity to time any machine up to 10 kva., and is adjustable from 0.1 to 5 sec. by a hand control covering any timing range which may be desired. The dial, which adjusts the timing period, is calibrated so that adjustment can be speedily made when switching from one thickness of metal to another.

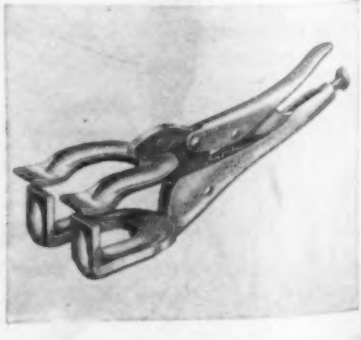
The timer makes it possible for a workman to produce a solid weld and eliminate defects common when the timing is left to the discretion of the operator, such as welds that will not hold due to short timing, burning or putting of the metal due to overtiming.

This low-cost Timatron will increase production, eliminate spoilage and reduce employee fatigue. Dimensions are 4¹/₄ in. deep, 5¹/₈ in. wide and 9 in. high.

WELDING CLAMP

A new, handy, locking welding clamp has been announced by Petersen Mfg. Co., DeWitt, Neb., makers of the popular VISE-GRIP Toggle Wrench.

The new clamp is said to simplify the welding of split fenders and most other welding jobs by quickly aligning the parts for welding, then locking to the work with both hands free for welding.



The tool is the regulation VISE-GRIP Toggle Wrench, but equipped with special deep-throated U-shape jaws which fit over the work, yet provide perfect visibility and working space for the welding operation.

The 2³/₄-in. throat permits the tool to reach well over the work. The jaws are quickly adjusted up to 1⁵/₈ in. for varying widths of material. The 9-in. clamp will retail for $2.95.

Resistance Welded

1000 or More *Every hour* on One "T-W" RESISTANCE WELDER

One man operating one T-W projection welder, equipped with dial feed (16 welding stations), produces 1000 or more loops every hour. *This is not unusual production for a Taylor-Winfield welder.*

This shock absorber is specifically designed for resistance welding. Your product or assembly may require slight alterations to use this high production process; *T-W men (without obligation) can show you how.*

Photos courtesy of The Gabriel Co., Cleveland, Ohio

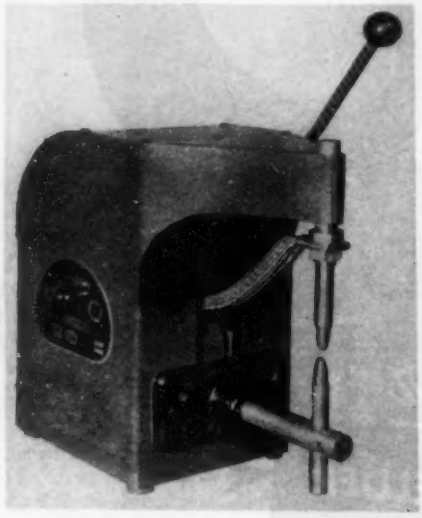
Taylor-Winfield offers many variations of dial feed press welders. Two of the features which make T-W dial feed equipment outstanding are; (1) Dial bearings which only carry mechanical loads (no welding current carried); (2) A series dual head circuit to make two welds simultaneously with less power than is required to make one weld with conventional equipment.

TAYLOR-WINFIELD
RESISTANCE WELDERS

THE TAYLOR-WINFIELD CORPORATION
WARREN • OHIO

SMALL SPOT WELDER

"Rex Junior," a simple, efficient and inexpensive bench model 1-kva. spot welder, is the newest member of the internationally famous Rex family of spot welders. No installation cost—it just plugs into any standard outlet carrying 110 v. a.-c. current.



It has an air-cooled transformer, removable standard No. 1 Morse taper tips, and welds up to 24 gage mild steel. Operation is controlled by a hand lever on the right side of the welder, but a foot-operated attachment will be provided if desired. Stands only 14 in. high and weighs approximately 76 lb. Throat depth is 6-in. and the lower horn is adjustable.

"Rex Junior" is ideal for sheet metal shops, jewelry radio repair and appliance repair shops, toy making, home workshops and all light manufacturing. The manufacturer, Rex Welder and Engineering Co., Kansas City, Mo., can also supply this same welder with a 220-v. transformer. Other spot welders for special applications and in sizes ranging up to 300 kva.

200-AMP. ENGINE-DRIVEN WELDER

A new Flexarc lightweight engine-driven welder, designed for 200 amp. at 30 v. on the basis of 50% duty cycle, is available from Westinghouse Electric Corp. Each welder comes with accessories complete ready to weld including work and electrode leads, helmet, electrode holder, a liberal supply of electrodes and a wire scratch brush.

Dubbed "The Ranger," this d.-c. welder can be towed anywhere a jeep can take it. The design characteristics of the generator provide easy striking and maintenance of the arc for shop quality welding on steel, cast iron, alloys, hard surfacing aluminum and brass.

The generator is direct-connected to a Hercules IXB engine. The welding current is adjusted over a wide range from 30 amp. at 20 v. to 250 amp. at 30 v. in four major steps by plugging screw-locking plugs on work and electrode leads.

Intermediate values of current are obtained by rheostat control. Polarity is positively controlled by interchanging work or electrode lead connections. Available either as a portable or stationary model.

Further information on this Flexarc engine-driven welder may be obtained from the Westinghouse Electric Corp., P. O. Box 868, Pittsburgh 30, Pa.

ALL-POSITION ELECTRODE

The improved Wilson No. 512 all-position, mild steel electrode is designed to produce weld metal possessing not only excellent mechanical properties, but also low hydrogen content.

This improved electrode has two advantages over its predecessor in that it can now be used on a.-c. and d.-c. reverse polarity current with the operating characteristics being equal. The former 512 electrode could only be used on D.-C. reverse. Secondly, preheating of this electrode is no longer required to obtain porosity-free weld deposits that are obtainable by using either the stringer bead or the full weave technique.

Recommended application for the improved Wilson 512 are: welding high sulphur, free machining steels; welding hardenable steels where no preheat is used; welding cold-rolled steels which normally exhibit excessive porosity when welded with conventional electrodes; weldments to be vitreous enameled after welding. The extreme low hydrogen content of this electrode makes possible the production of satisfactorily enameled surfaces without any heat treatment prior to enameling.

Further information on the improved Wilson No. 512 electrode can be obtained by writing directly to Dept. 1543P Wilson Welder and Metals Co., Inc., 60 East 42nd St., New York 17, N. Y.

WROUGHT IRON

A 20-page illustrated booklet that describes wrought iron, oldest ferrous metal known to man, has just been made available for distribution by A. M. Byers Co., Pittsburgh. The title is "The ABC's of Wrought Iron."

The booklet tells in nontechnical terms what wrought iron is, why it resists corrosion and withstands shock and vibration, how it is made, and how it is bent, welded and threaded. The various services for which wrought-iron pipe and plates are used are depicted.

AMPCO ELECTRODE

Ampco Metal, Inc., Milwaukee 4, Wis., announces a new silicon bronze arc-welding electrode, "Sil-Trode." It was developed especially to meet the needs of welding engineers who prefer to use an electrode of similar composition to the parent metal when fabricating and repairing silicon bronze parts.

Sil-Trode is a shielded-arc silicon bronze electrode operating on reverse (positive) polarity, direct current. The coating and core wire were specifically designed to produce a spray type arc action, low spatter loss, free-flowing slag, and weld metal producing crack-free, smooth, dense deposits. The slag is friable and easily removed.

Sil-Trode is primarily recommended for the metallic-arc welding of silicon bronzes although, like most other bronze electrodes, it may be used to weld copper, dissimilar metals and ferrous-base metals. This electrode conforms to the proposed A.W.S.-A.S.T.M. specification E Cu Si.

The special core wire selected for use in the Sil-Trode was carefully developed so that the electrode could be used in joining any of the present weldable grades of silicon bronze sheet and plate available for fabricated tanks, chemical processing equipment, etc.

Sil-Trode will be available in $^3/_{32}$-, $^1/_8$-, $^5/_{32}$-, $^3/_{16}$-, and $^1/_4$-in. diameter sizes and packed in 50-lb. containers.

Information on Sil-Trode will be sent on request.

PUBLIC HEARING PLANNED BY THE A.S.M.E. BOILER CODE COMMITTEE

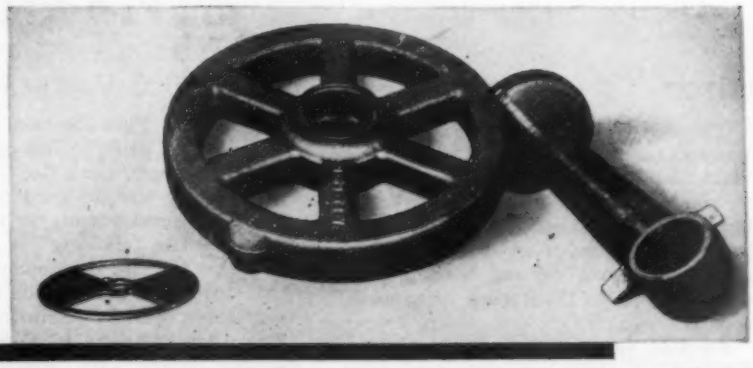
In the April issue of *Mechanical Engineering* announcement was made by the Boiler Code Committee of The American Society of Mechanical Engineers that its Special Committee to Revise Section VIII of the A.S.M.E. Boiler Construction Code has prepared and submitted in draft form the Proposed Revision of Section VIII of the Code (Unfired Pressure Vessel Code), dated January 1947. Public hearings have been held in May at Houston, Texas, and Los Angeles, Calif., where some 250 representatives exchanged views on the proposed revision.

The Boiler Code Committee will hold another public hearing in the East on the Proposed Revision of Section VIII in the Engineering Societies Building, 29 West 39th St., New York, N. Y., on November 19, 1947 at 10:00 A.M. The purpose of this hearing is to give all those interested in the proposed revision an opportunity to express verbally their comments. The Boiler Code Committee is particularly desirous of attracting to this meeting all users of the A.S.M.E. Unfired Pressure Vessel Code, such as pressure vessel manufacturers and users, representatives from the petroleum industry and state officials.

Those desiring to review the proposed revision may obtain copies from the A.S.M.E. at 29 West 39th St., New York 18, N. Y., at $1.00 each. All those interested are also invited to submit their written comments to the Secretary of the Boiler Code Committee.

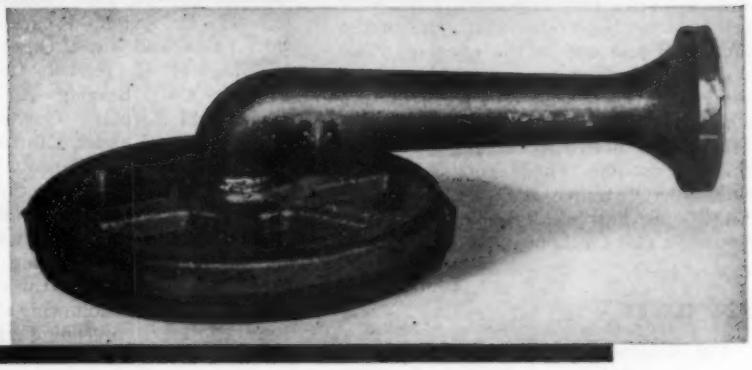
How NI-ROD saved a headache...

and brought a saving



BEFORE:

Parts of burner assembly for Luxaire gas-fired gravity furnace made by C. A. Olsen Mfg. Co., Elyria, Ohio.



AFTER:

Completed burner showing parts welded in place by Ni-Rod. Note smoothness of welds. Steel disc was joined to mouth of cast iron throat inlet by 4 tack welds 90 degrees apart.

IN ASSEMBLING the burners for their new "Luxaire" domestic gas furnaces, the C. A. Olsen Mfg. Co., of Elyria, Ohio, ran into trouble.

Ordinary cast iron electrodes wouldn't do the job of welding the cast iron burner heads to the burner throats. Welds cracked... parts failed.

After experimenting with many different electrodes, they finally discovered their solution . . . in NI-ROD.*

Ni-Rod, they found, united the two cast iron parts with strong, sound, crack-free welds.

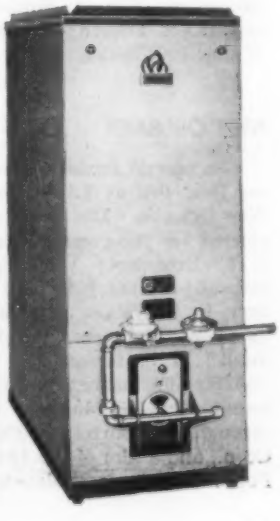
It also welds cast iron to steel. So, the Olsen Company had no trouble in welding the slotted steel discs to the cast iron throat inlets . . . in the same operation.

And, while improving their product, Ni-Rod also brought money- and labor-saving advantages. For example, Ni-Rod goes on so smoothly that extra finishing operations are unnecessary. The whole job is completed in a little more than a minute . . . without preheating . . . using only half an $\frac{1}{8}$" electrode.

Today, the Olsen Company reports that over 25,000 units have been welded with Ni-Rod and are giving A-1 service.

Find out more about Ni-Rod . . . how it can speed your production . . . save extra operations . . . save extra cost. Available in $\frac{3}{32}$", $\frac{1}{8}$", $\frac{5}{32}$", and $\frac{3}{16}$" diameters. Order a 5-lb. package from your nearest distributor listed below.

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y. *Reg. U.S. Pat. Off.



"Luxaire" Series G Gas Fired Domestic Gravity Furnace Size: 5 ft. x 2 ft. x 3 ft. Output: 60,000 to 90,000 AGA B.T.U.

EMBLEM OF SERVICE
INCO NI-ROD TRADE MARK

SEND FOR INSTRUCTION BOOKLET

Get NI-ROD from:

WHITEHEAD METAL PRODUCTS COMPANY, INC.
WILLIAMS AND COMPANY
STEEL SALES CORP.
HENDRIE & BOLTHOFF MFG. & SUPPLY CO.
PACIFIC METALS COMPANY, LTD.
J. M. TULL METAL & SUPPLY CO.
EAGLE METALS CO.
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SECTION ACTIVITIES

DETROIT

Through the courtesy of Fisher Body an inspection trip was made through their Plant No. 1 by members and guests of the Detroit Section and the Saginaw Valley Division on September 11th. The visitors had an opportunity to see spot, projection, gun and arc welding and brazing techniques used in fabricating automobile bodies.

Through the courtesy of the Kaiser-Frazer Corp., two inspection trips were arranged on September 12th, one in the afternoon and one in the evening. The visitors were given an opportunity to see first hand, the welding technique used by a large automobile manufacturer. Kaiser-Frazer also obligingly arranged to show the Kaiser movie "The History of Building the Liberty Ships at Richmond Ship Yard." Several welding techniques are shown in this excellent movie.

NEW JERSEY

The September dinner meeting of the New Jersey Section was held on the 16th at the Essex House, Newark, N. J. Subject of the meeting was "Shall It Be: Cast? Forged? or Welded?" The speaker was Norman L. Mochel, Metallurgical Engineer, Westinghouse Electric Corp., Philadelphia. Mr. Mochel discussed the factors to be considered in the selection of castings, forgings or weldments for construction or fabrication of various types of industrial equipment. Mr. Mochel's discussion was of great value in clarifying the problem of which method is most suitable for specific applications in the field of "Heavy Industry."

KANSAS CITY

The following officers have been elected by the Kansas City Section for 1947–48: Chairman, Wm. J. Snider; Vice-Chairman, Cecil Poarch; Secretary-Treasurer, Wilbur F. Wheeler.

NEW ORLEANS

The annual business meeting was held on June 6th at Lawrence's Restaurant, New Orleans. The following officers were elected for the coming year: Chairman, J. F. Houppert; Vice-Chairman, C. O. Stilwell; Secretary, Donald Sarrat; Treasurer, R. P. Wilson; Program Committee, James W. Chambers; Asst. Program Chairman, J. H. Patterson.

After the business meeting two color, sound films—"Making Pipe" shown through the courtesy of the A. O. Smith Corp., and a film of the 1947, Sugar Bowl Football Game were shown.

NEW YORK

The New York Section opened its season with a panel session on Sept. 19th with the subject "Let's Get Up to Date." The meeting was designed to report on the latest developments in welding and cutting. The following six experts reported on the new developments in their particular fields, after which the meeting was thrown open for discussion and questions: Arc Welding—E. Vom Steeg, Jr., General Electric Co.; Resistance Welding—H. B. Axtell, Progressive Welder Co.; Gas and Inert Gas-Shielded Arc Welding—H. T. Herbst, the Linde Air Products Co.; Brazing—A. M. Steapen, Handy and Harman; Gas and Arc Cutting—Charles Kandel, Craftsweld Equipment Corp.; Miscellaneous Processes—A. N. Kugler, Air Reduction Sales Co. H. O. Klinke, Apparatus Research Dept., Air Reduction Sales Co., was Technical Chairman for the meeting. Questions from the audience kept the experts busy for nearly an hour following their talks.

At a dinner preceding the meeting, past-chairman pins were presented to all past chairmen of the Section who were able to attend. Pins are being mailed to the other past chairmen.

PHILADELPHIA

The Philadelphia Section Special Activities Committee announces the following schedule of meetings for the coming year:

October 3rd, Metallurgy for Welders, R. D. Thomas, Jr.

November 7th, Resistance Welding, O. C. Fredericks, Education Sub-Committee.

December 5th, Electrodes and Machines, John Lang.

February 6th, Automatic Welding Applications, Walter Mehl.

March 5th, Resistance Welding, O. C. Fredericks, Education Sub-Committee.

April 2nd, Stresses and Simple Structures, A. A. Holzbaur.

May 7th, Resistance Welding, O. C. Fredricks, Education Sub-Committee.

These meeting are in addition to the regular monthly meetings which are held on the third Monday of each month, and are designed to supply technical information to restricted groups. The program, under the Chairmanship of Mr. A. A. Holzbaur, Welding Supervisor, Sun Shipbuilding and Dry Dock Co., Chester, is in its fourth year and have proved a very successful activity for the Section.

The regular monthly meeting of the Section was held on September 15th at the Engineers' Club. W. G. Theisinger of the Lukens Steel Co., Coatesville, spoke on the subject "Welding Clad and Alloy Steels."

ROCHESTER

The following is a list of newly appointed officers of the Rochester Section: Chairman, Edward Jones; Vice-Chairman, Robert Raudebaugh; Sec.-Treas., Walter Dick; Membership Committee Chairman, Harry Stoler.

SYRACUSE

The September meeting held on the 10th at the Hotel Syracuse was addressed by H. S. Swan of the American Locomotive Co. Mr. Swan spoke on the subject "Welding Steam and Diesel Locomotives."

The October meeting will be held on the 15th and will be addressed by LaMotte Grover of the Air Reduction Sales Co., who will speak on "Structural Steel Welding."

TOLEDO

In addition to the newly elected officers for the Toledo Section published in the September Journal, the following were also elected: 2nd Vice-Chairman, W. H. Marion; Delegates to Toledo Technical Council—E. V. Newman, Edwin Nafzger, Alternate.

Meetings will be held on the Second Tuesday of each month from September to May.

WESTERN MASSACHUSETTS

The following officers and committee chairmen have been appointed for the fiscal year by the Western Massachusetts Section; Chairman, Sidney Low; Vice-Chairman, Thomas Dyer; Secretary, Albert E. Labossiere; Treasurer, Howard W. Walsh; Program Committee, Thomas Dyer; Membership Committee, Gordon Clark.

WESTERN NEW YORK

The following officers and committee chairmen have been appointed for the fiscal year by the Western New York Section Chairman, Clarence E. Jackson; Vice-Chairman, Odgen C. Mills; Treasurer, Robert Siemer; Program Committee, Charles Jennings.

The Section reports that they have had an after-dinner speaker or a movie on a current welding problem or idea for the past year and this has increased the dinner attendance a great deal. The Section is proud of its 30% increase in attendance at the regular Meetings and they are going to attempt to better this increase.

YORK-CENTRAL PENNSYLVANIA

G. A. Ostrom has been appointed as Section Secretary to fill the unexpired term of W. H. Lackey, who has been transferred to the Pittsburgh area.

ABSTRACTS OF CURRENT WELDING PATENTS

Prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of patents, Washington 25, D. C.

2,424,892—Electric Resistance Welding Fixture—Sven Malke, inventor, Milwaukee, Wis., assignor to A. O. Smith Corp., Milwaukee, Wis. (12 claims)

The patented welding fixture includes an electrode adapted to apply welding pressure to two different joints to be welded simultaneously. The fixture is adapted to adjust itself to equalize the pressure applied to the two joints.

2,425,183—Controller System for Electric Welding Apparatus—Leo C. Hall, inventor, Cincinnati, Ohio. (1 claim)

Hall's control apparatus relates to a welding system using a d.-c. generator having a separate exciting current supplied to the field winding of the generator. A discharge device is provided with its anode and cathode elements being connected in the field winding exciting current and the grid circuit thereof connects to an independent current supply which has a variable resistor therein for modifying the field winding exciting current to govern the generator current as desired.

2,425,690—Welding Head Shield or Helmet—John Strong, inventor, Hyde, England. (2 claims)

This patent relates to means provided on each side of the mask portion of the welder's helmet for removably and pivotally attaching the mask to the head harness of the helmet.

2,425,709—Blowpipe Nozzle—James H. Bucknam and Ivan P. Thompson, inventors, assignors to The Linde Air Products Co. (17 claims)

The patented nozzle includes an elongated member having a central oxygen passage extending longitudinally therethrough and having a plurality of acetylene passages arranged in circumferentially spaced substantially parallel relation to the oxygen passage. All of the passages terminate at one end of the elongate member and an end cap is provided for directing acetylene discharged from the acetylene passages inwardly toward the oxygen which discharges as a single stream from the discharge end of the oxygen passage.

2,425,710—Blowpipe Nozzle—James H. Buchnam, Cranford, N. J., and Ivan P. Thompson, Elizabeth, N. J., inventors, assignors to The Linde Air Products Co. (10 claims)

In this patent, a post-mixed desurfacing blowpipe nozzle is covered and it has a first single oblong discharge orifice for oxygen that connects to an oxygen supply passage upstream and axially in line with said orifice. An outlet portion upstream of the first orifice is provided and gradually merges with such first orifice which first orifice gradually changes from circular to enlarged oblong cross section adjacent its end. Fuel gas supply passages are formed in the nozzle and discharge into enlarged chambers adjacent the enlarged portion of said discharge orifice and restricted passage means communicate between said fuel gas chambers and the enlarged portion of the oxygen orifice.

2,425,830—Adjustable-Electrode Arc-Welding Torch—Elmer R. Ross, inventor, San Diego, Calif., assignor to Solar Aircraft Co. (2 claims)

Ross' torch comprises a handle having two parallel electrode supporting rod members projecting from one end thereof adapted to support a pair of electrodes for movement toward and away from each other. The handle is provided with special mounting means for controlling rod members extending therefrom.

2,426,280—Welding Machine—Leonard E. Nickols, inventor, Birmingham, Mich., assignor to Resistance Welder Corp. (7 claims)

A resistance welding machine including a combination center ram and conductor, an outer conductor insulated from the first conductor and arranged concentrically thereabout, and pressure-actuated means for reciprocating the center conductor are provided in this patent. A "work" accommodating opening is provided in the outer conductor.

2,426,481—Tank Wagon Welded in One Piece—Nils Albin Andersson, inventor, Alsten, Sweden, assignor to A/B Chr. Olsson. (4 claims)

A tank wagon having a plurality of trucks, a cylindrical shell serving as an interframe between the trucks and a pair of parrallel side plates is provided. The side plates serve as axle box mountings and are welded to the outside of the shell.

List of New Members

August 1 to August 31, 1947

BIRMINGHAM

Pearson, Alfred E. (A), Ingalls Shipbldg. Corp., Birmingham, Ala.

CHICAGO

Neil, Marshall E. (C), Mid-States Equipment Corp., 2429 S. Michigan Ave., Chicago 16, Ill.

COLORADO

Westerkamp, R. M. (C), Westerkamp Express, 5003 Grant St., Denver, Colo.

DAYTON

Benedick, Dawson J. (C), 315 Dell St., Dayton 4, Ohio.

Tyree, Emory J. (B), International Harvester Co., 2069 Lagonda Ave., Springfield, Ohio.

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Yes, modern, functional design has caught up with d-c welders, and you'll probably want to know more about the results—the new WD-40 series machines, manufactured in 200-, 300-, and 400-amp models. Just mail the coupon to your nearest G-E Arc Welding Distributor; why not right now! *Apparatus Department, General Electric Company, Schenectady 5, N. Y.*

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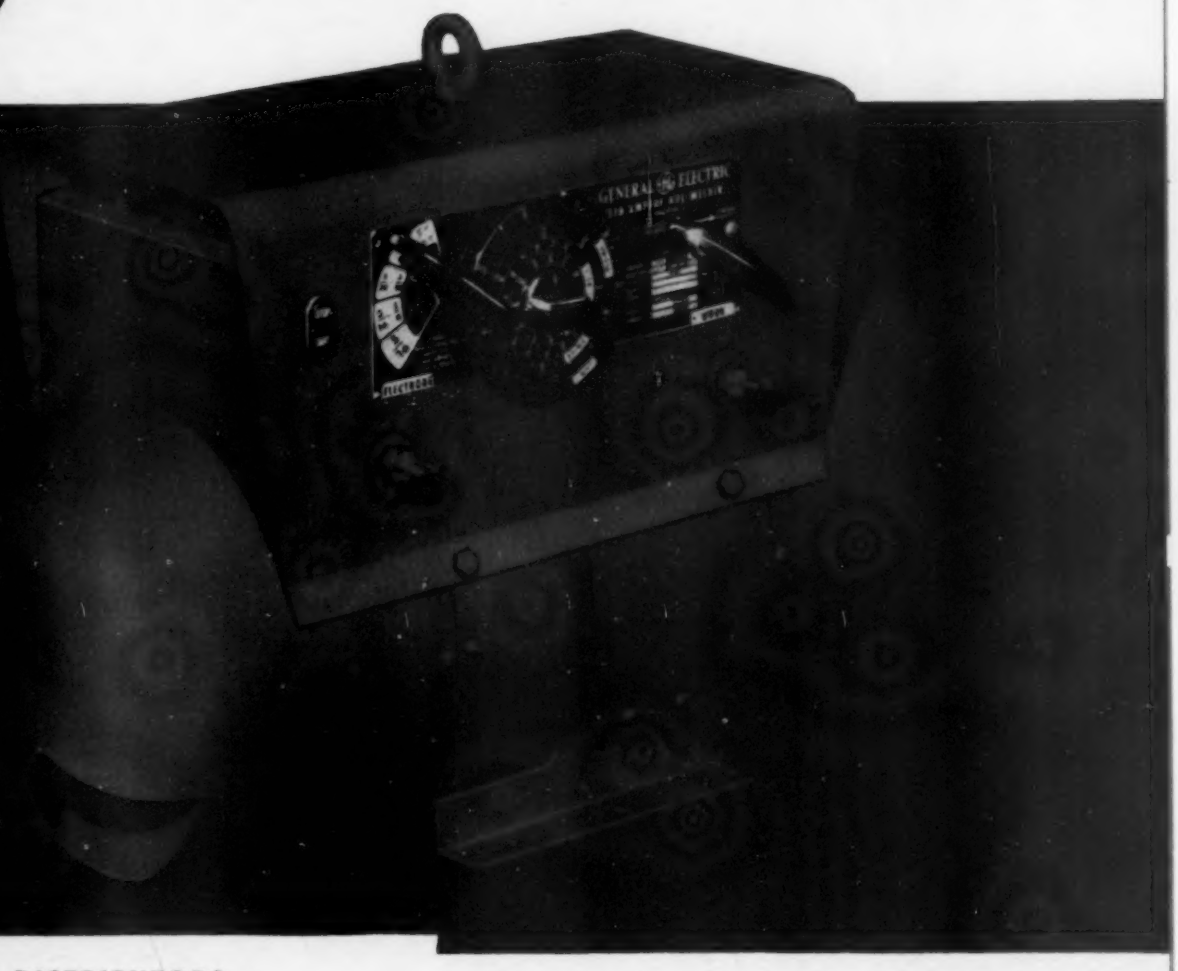

G-E ARC-WELDING DISTRIBUTORS

ABAMA—Young & Vann Supply Co., Box 2532, Birmingham;
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ZONA—Arizona Welding & Equipment Co., 230 So. Central Ave., Phoenix
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ORADO—Hendrie & Bolthoff Co., 1635 17th, Denver (also WYO.)
RIDA—Cameron & Barkley Co., Tampa
RGIA—Chandler Machinery Co., 120 Houston N.E., Atlanta;
Georgia Oxygen Co., 521 Fifth, Macon
HO—Olson Manufacturing Co., 2223 Fairview Ave., Boise
NOIS—Machinery & Welder Corp., 1324 W. Fulton, Chicago
(also MINN. and WIS.)
IANA—Sutton-Garten Co., 301 West Vermont, Indianapolis;
Perry Welding Sales & Service Co., 424 East Monroe, South Bend
NSAS—Watkins, Inc., 204 North Waco, Wichita
NTUCKY—G.E. Supply Corp., Harlan;—Mine Service Co., Lothair;
Marine Electric Co., 110 South First, Louisville
ISIANA—Equitable Equipment Co., 410 Camp, New Orleans;
Hughes Welding & Supply Co., Box 116, Shreveport
RYLAND—Arcway Equipment Co., 920 E. Fort Ave. Baltimore
(also DEL. and VA.)
HIGAN—Welding Sales & Engineering Co., 8570 Grinnell Ave., Detroit;
ller Welding Supply Co., 55 Mt. Vernon Ave., Grand Rapids
SOURI—Hohenschild Welders Sup. Co., 512 E. 18th, Kansas City (also KAN.)
Machinery & Welder Corp. 700 So. Spring Ave., St. Louis (also IOWA)
NTANA—Montana Hardware Co., 823 South Montana, Butte
BRASKA—Lincoln Welding & Supply Co., 330 South 10th, Lincoln;
Omaha Iron Co., 13th & Harney, Omaha (also IOWA)
W ENGLAND—Welding Engrng. Sales Corp., 150 Causeway, Boston, Mass.
W MEXICO—Industrial Supply Co., 104 So. Cornell Ave., Albuquerque
W YORK—Welding Engineering Sales Corp., 110 E. 42nd St., New York
RTH CAROLINA—National Welders Supply Co., 1230 So. Tryon, Charlotte
RTH DAKOTA—Dakota Electric Supply Co., 1017-1023 Fourth Ave. N., Fargo
O—Burdett Oxygen Co., 3300 Lakeside Ave., Cleveland;
Hanna Welding Co., 1102 W. Central Ave., Toledo
LAHOMA—Welders Supply Co., 422 So. Walker, Oklahoma City
GON—J. E. Haseltine Co., 115 S.W. Second Ave., Portland (also WASH.)
NSYLVANIA—Arcway Equipment Co., 49th & Grays Ave., Phila. (also N. J.)
UTH CAROLINA—Cameron & Barkley Co., 84 Sheppard, Charleston
NNESSEE—Welding Gas Products Co., 821 E. 11th, Chattanooga;
Volta Oxygen Co. 786 Madison Ave., Memphis
AS—J. Ernest Strout & Co., 501 E. 3rd Ave., Amarillo;—Briggs-Weaver Machinery Co., 309 No. Market, Dallas;—Texas Welding Supply Co., 1302 Mc[illegible]ney, Dallas;—Car Parts Depot, Inc., 712 Texas, El Paso;—Fort Worth Welding & Supply Co., 2228 No. Main, Fort Worth;—G.E. Hou[illegible]n Welding Division, 5931 Clinton Dr., Houston;—San Antonio Mach[illegible] & Supply Co., 325 No. Centre, San Antonio
—The Gallagher [illegible], 48 So. Second E., Salt Lake City
VIRGINIA—Blue[illegible]ld Supply Co., Bluefield; Logan Hardware, Logan;
Virginian Electric, [illegible]., Box 2833, Charleston
ALL—W. A. Ramse[illegible] Ltd., Box 1721, Honolulu, T.H.
ADA—The Canadi[illegible] General Electric Co., Toronto
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Baker, Richard (B), Tipaloy, Inc., 1435 E. Milwaukee, Detroit 11, Mich.
Bierer, P. R. (B), Tipaloy, Inc., 1435 E. Milwaukee, Detroit 11, Mich.
Boddy, G. Howard (B), Tipaloy, Inc., 1435 E. Milwaukee, Detroit 11, Mich.
Boelter, L. W. (A), Ford Motor Co., 3000 Schaefer Rd., Dearborn, Mich.
Hassler, J. (B), 8114 Rathbone, Detroit 9, Mich.
Kuhn, Frank (B), 6110 Cass Ave., Detroit 2, Mich.
Miller, D. C. (B), Tipaloy, Inc., 1435 E. Milwaukee, Detroit 11, Mich.
Winton, D. O. (B), 8882 Piedmont Ave., Detroit 23, Mich.

HARTFORD

Jaeger, Alden M. (C), 63 Benham St., Torrington, Conn.

INDIANA

Stevens, George (B), Lincoln Electric Co., 3343 N. Central Ave., Indianapolis, Ind.

KANSAS CITY

Bleistein, Charles H. (C), Everitt-Bleistein Assoc., Architects & Engineers, 1221 R. A. Long Bldg., Kansas City, Mo.

LEHIGH VALLEY

Lehr, Alton E. (B), 304 Dorchester Ave., Lincoln Park, Pa.

LONG BEACH

Irwin, A. G. (C), 2439 Orange Ave., Long Beach, Calif.

LOS ANGELES

Corbitt, Charles M., Jr. (C), 714 W. Olympic Blvd., Los Angeles 15, Calif.
Marking, L. Paul (C), 1208 Montebello Blvd., Montebello, Calif.

MAHONING VALLEY

Green, Andrew (B), Youngstown Steel Car Corp., Niles, Ohio.

MARYLAND

Burnley, James H. (C), 200 Scott St., Baltimore 3, Md.

MICHIANA

Burke, L. R. (B), Clark Equipment Co., Buchanan, Mich.
Deming, George T. (B), Clark Equipment Co., Buchanan, Mich.
Flenar, Otis M. (B), 210 N. Detroit St., Buchanan, Mich.
Morganthau, William (B), Clark Equipment Co., Buchanan, Mich.
Turner, George L. (B), Clark Equipment Co., Housing Division, Buchanan, Mich.

NEW YORK

Hames, George J. (C), Cutler-Hammer, Inc., 430 Southern Blvd., New York, N. Y.
Krivobok, V. N. (B), International Nickel Co., 67 Wall St., New York 5, N. Y.
Wheatley, John G. (C), Eagle-Globe-Royal Indemnity Co., Engrg. Dept., 150 William St., New York 8, N. Y.

NORTHWEST

Woods, Carl E. (B), Super Six Mfg. Co., 4026 Washington Ave. N., Minneapolis 12, Minn.

OKLAHOMA CITY

Lippincott, Lloyd (B), Independent Supply Co., Box 1481, Oklahoma City, Okla.

PASCAGOULA

Bond, N. L. (C), 310 8th St., Pascagoula, Miss.
Millikan, H. J. (C), 1401 Tyler Ave., Pascagoula, Miss.
Moore, V. E. (C), 422 Lake Ave., Pascagoula, Miss.

PEORIA

Hanson, Melvin A. (B), G. M. & O. Shops, Bloomington, Ill.

PHILADELPHIA

Turner, Howard D. (C), Lukenweld, Inc., 488, Coatesville, Pa.

PITTSBURGH

Semmer, M. R. (C), Weber-Semmer Co., 5108 Liberty Ave., Pittsburgh 24, Pa.
Synder, Saylor C. (B), 1126 Frick Bldg., Pittsburgh, Pa.
Zern, R. A. (B), Cook & Zern Consulting Engrs., 607 Wabash Bldg., Pittsburgh 22, Pa.

PUGET SOUND

Freeman, Lester I. (C), Acme Steel & Welding Co., 506 S. F St., Aberdeen, Wash.

ST. LOUIS

Day, Thomas W. (C), Lincoln Electric Co., 4427 Manchester, St. Louis, Mo.

SAN FRANCISCO

Flaherty, Dewey F. (C), 2323 20th Ave., San Francisco, Calif.
O'Massey, Richard Conrad (C), 333 Mt. Vernon Ave., San Francisco 12, Calif.
Popert, William H. (C), American Inst. of Steel Constr., 712 Mechanics' Institute Bldg., 57 Post St., San Francisco 4, Calif.

WASHINGTON

Bond, Howard C. (C), 2210 Nicholson St., S. E., Washington, D. C.
Semon, Howard W. (C), 1130 Maryland Ave., N. E., Washington 2, D. C.

NOT IN SECTIONS

Brewster, Edward D. (B), Aptdo. Postal 1240, Mexico, D. F.
Burda, Jan (B), Ostrava 8, Zabreh Ruska 131, Czechoslovakia.
Hanks, Edmund E. (C), 405 Jefferson Standard Bldg., Greensboro, N. C.
Hauser, Hans J. (C), 37 Seidenstrasse, Winterthur, Switzerland.
Jan, Ing. Mandaus (B), Prauge VIII, Ckd, Czechoslovakia.
Take, P. H. (B), Halifax Shipbldg. Co., c/o D. Scouler, Halifax, Nova Scotia.

Members Reclassified

During Month of August

CHICAGO

Chouinard, A. F. (B to A), 1200 N. Claremont, Chicago, Ill.

COLORADO

Rosenbach, Aleck (C to B), 3600 Race St., Denver, Colo.

Zigler, Alex R. (C to B), 3434 Humboldt, Denver, Colo.

NEW YORK

Kelly, George (C to B), 468 E. 160 St., Bronx 56, N. Y.

Moles, Edward W. (C to B), 130-07—228th St., Laurelton 13, N. Y.
Muller, Albert (C to B), 115[illegible] E. 26th St., Brooklyn 10, N. Y.
Weigel, A. C. (B to A), Combustion Engrg. Co., 200 Madison Ave., New York, N. Y.